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Blue Streak

This Society has never concerned itself with military matters. It may be that eventually we shall have to do so to some extent, if man's venture into space ceases to be ostensibly for exploration and scientific research and is undertaken blatantly as the natural development of the struggle for power upon the Earth. But until that day we are not concerned directly with missiles as missiles, nor with questions of military strategy.

Because of this, we do not intend to comment at length on the Government's expressed reasons for the cancellation of the Blue Streak ballistic missile programme. We will only remark in passing that it seems strange that neither America nor Russia is following our example and abandoning land-based missiles, and it is equally strange that it is the existence of just these Russian missiles which has sparked off the cancellation.

However, the Society is very much interested in Blue Streak as a vehicle, and we state quite bluntly that to abandon its development completely and hand it over to the scrap merchants would be disastrous.

To begin with, complete abandonment would be a most callous affront to all those who have worked on Blue Streak for so long. Inevitably some must lose their jobs or be diverted to other tasks. This has happened on other occasions with other technical projects but hardly ever in such a spectacular way, or at such a stage in development. Blue Streak is Britain's first "large" rocket and just ready for its first flight. Justice to the designers and constructors demands that at least one rocket shall be fired so that they may at least have the satisfaction of knowing that their expectations have been fulfilled. We have every confidence that the launching would be successful—the "fiasco" of Blue Streak to which the press is fond of referring, is certainly not a technical one.

The money expended on this firing (measured only in tens of thousands, not millions, of pounds) would not be wasted, for it would be possible to carry a payload of instruments for upper atmosphere research. And that leads us to our next point.

Although no information has been released concerning this aspect of the programme, there must be several Blue Streak rockets in an advanced stage of construction or assembly. These could well form the basis of a British Spaceflight Programme.

We believe that it is essential for Britain to undertake such a programme and to begin it as soon as possible. On several occasions in this *Journal* and elsewhere the Society has made this clear, but unfortunately with little effect. In view of the urgency of the matter, it was therefore decided to submit a memorandum to the Prime Minister and this is reproduced on pp. 328-330 of this issue.

This memorandum was submitted to Mr. Macmillan some weeks before the cancellation of the ballistic missile programme was announced. At the time of writing it is still under consideration, and on 10 May the Minister for Science received a deputation from the Society to amply and discuss the proposals.

We earnestly hope that the Government will reach a favourable decision and approve the adaption of Blue Streak for research purposes. If this is done, then in the end the "fiasco" might prove to have been a blessing. Although the development of ballistic missiles has contributed much to astronautics, their stockpiling would contribute little, and their use in nuclear warfare would mean the end of civilization. But a space research programme will enable us to keep abreast of this new technology, while peaceably *using* the vehicles.

Space Medicine Symposium

In October, 1958, the Society organized the first Space Medicine Symposium. At the time, one of the country's leading scientific publishers requested permission to publish the proceedings of the Symposium as a book, and an agreement was made to this effect. Owing to the slow rate of progress, Council found it necessary to terminate this arrangement towards the end of 1959, and as a result the proceedings now appear in this enlarged issue of the *Journal*, originally planned by the Editor as a "double number" for April/June. Although publication of the special April issue rendered the combined issue unnecessary, it was decided to continue as planned, as it was obviously desirable that all the Space Medicine Symposium papers should appear within a single cover.

We offer our apologies to both speakers and readers for the delay in publication. Since the papers were written, new knowledge has become available but because of the number of authors involved it would have been impracticable for major changes to have been made to the text without causing further delay. Some of the papers are printed here in an abbreviated form; again, it was not found possible in the time available for these authors to include the additional material they had presented verbally. However, we believe that despite these shortcomings members and others will be glad to have a record of the Symposium.

A pleasing feature of the Symposium was the important contribution made by various Government establishments, and in particular the R.A.F. Institute of Aviation Medicine. This is, of course, entirelyappropriate, for when Britain does get a manned spaceflight programme, the R.A.F. is the obvious body to supply the astronauts. Much of the present-day work in progress at the Institute will be of importance in astronautics.

G. V. E. THOMPSON

SOME BLAST STUDIES WITH APPLICATION TO EXPLOSIVE DECOMPRESSION*

By Professor CARL-JOHAN CLEMEDSON,† M.D., Fellow

(Communication from Research Institute of National Defence, Sweden.)

ABSTRACT

The similarities and dissimilarities between explosive decompression and blast injury are discussed. The qualitative changes in respiration and circulation, as well as the pathological changes in the lungs, are the same in these two kinds of trauma. The reflex mechanism mediating the physiological changes may differ, however, and in blast a direct mechanical effect on the heart seems to play a greater role than in explosive decompression.

The bio-mechanical events which result in the pathological and pathophysiological changes are supposed to differ in the two conditions, but more research is necessary in order to verify this assumption.

LANGTON[1] has given a comprehensive account of meteors and the hazard of meteorite collision in space travel. Even if, with reasonable assumptions as to the geometry of the vehicle, duration of the journey and other relevant factors, the meteorite collision risk can be supposed to be small, it is a statistical phenomenon and, therefore, the chance of a hit will never be equal to zero. In a space vehicle with no meteorite bumper screen,[2] a meteorite travelling at very high velocity would be likely to blow open a large hole in the hull, due to thermal penetration, with an explosive decompression as a consequence. The risk will probably increase with the use of prospective more powerful propellents, and especially when starting from an artificial satellite so that greater velocities can be acquired by the vehicle. Although not one of the most important problems in space medicine, the potential danger of explosive decompression must be seriously considered, as the rescue of a crew after an explosive decompression in the void of space seems to be an almost insoluble problem. Exposure of the crew to other rapid pressure phenomena should also be taken into consideration.

In aviation medical research, rapid decompression has attracted much interest, and extensive studies within this field have been made during the last twenty years in many countries, *e.g.*, in Austria,[3] France,[4] in Germany[5] during the war, and especially in the United States.[6–13] The pathologico-anatomical and pathophysiological changes in explosive decompression, therefore, are rather well known, but there are still many gaps in our knowledge, especially concerning the biophysical events that result in these changes. It is, thus, not known whether the lung lesions that may occur after an explosive decompression are caused by an overdistension under excessive intrapulmonary pressure or whether the injuries are the result of a contusion by a pressure or shock wave of similar kind as in a blast exposure.[14]

In our laboratory we have been studying the biomedical effects of high explosive and compressed air shock waves during the last ten years and we have exposed small laboratory animals (especially rabbits, rats and guinea-pigs) to blast waves in open field blastings and in shock tubes in the laboratory. The use of the detonation chamber inside the laboratory facilitates the recording of physiological parameters (respiration, blood pressure, heart activity, brain activity, etc.) and of the shock wave pattern in various parts of the body. The chief goal has been to study the effects of the shock wave on the physiological functions of the body.[15–17] Recently we have also started some work with the aim of trying to elucidate the biophysical mechanism of the pulmonary damage in blast.

During these studies on the pathological and pathophysiological effects of shock waves, it was realized that there were many similarities between the damage caused by blast and that resulting from an explosive decompression. This has also been pointed out by other authors. In air blast injury, the most conspicuous pathological changes are found in the lungs and consist of haemorrhages and traumatic emphysema. Luft and Bancroft,[14] reviewing the literature on rapid decompression, found that histological lung damage invariably occurs in experimental animals if the time characteristic of the decompression is 0·01 sec. or less and with a fractional differential, *i.e.*, the ratio (pressure difference/initial pressure before decompression) of 0·6 or more.

The most impressive physiological changes occurring immediately after exposure to a strong shock wave concern respiration and circulation.[18] Respiration becomes very rapid and shallow and often also irregular. Sometimes there is an apnoea period of several seconds following immediately after the detonation. Within a few seconds after the detonation, a pronounced, but usually rather short-lasting bradycardia is seen, and the blood pressure drops to fairly low values. Extrasystoles are rather common.

Fig. 1 shows the changes in respiration of a rabbit exposed to a strong shock wave. Immediately after the detonation the respiration becomes very rapid and shallow and also somewhat irregular. Respiration may remain heavily changed for several hours or even the

* Paper read at the Space Medicine Symposium, 16-17 October, 1958.

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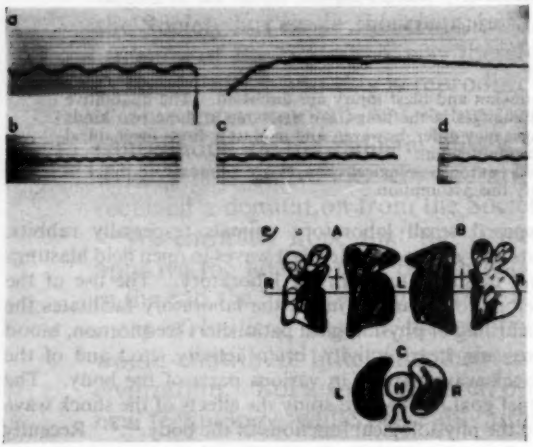

FIG. 1. Respiratory curve of a rabbit exposed to a shock wave with a peak pressure of 11·2 atm. reflection overpressure. Curve *a*: before, during and until 8 sec. after detonation (at arrow); *b*: 20 sec.; *c*: 1·5 min. and *d*: 2·5 min. after detonation. Time between vertical lines, 0·1 sec. *e*: Schematic drawing of the lungs, showing the degree of pulmonary haemorrhages.

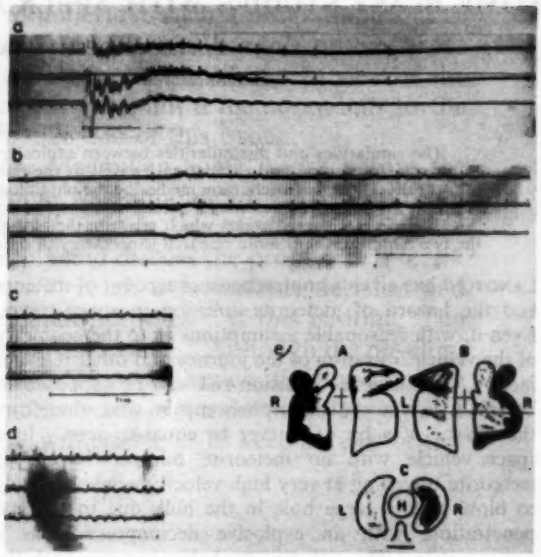

FIG. 2. Electrocardiogram of a rabbit exposed to a shock wave with a peak pressure of 11·9 atm. reflection overpressure. Curves *a* and *b* are obtained before and until 25 sec. after the detonation, which occurred at the sharp distortion in the curves. *c* was recorded 1·5 and *d* 3·5 min. after detonation. *e*: Schematic figure showing degree of lung haemorrhages.

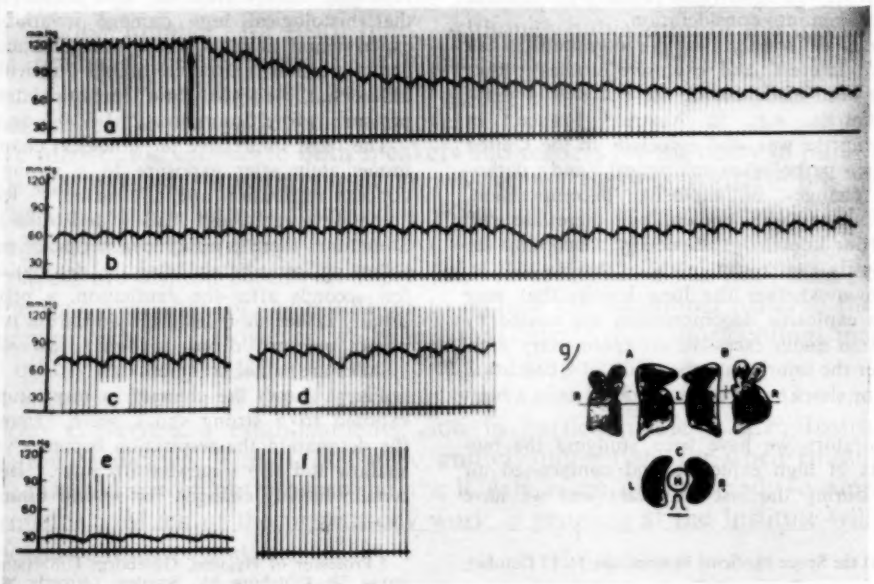

FIG. 3. Blood pressure in left carotid artery of a rabbit exposed to a peak shock wave pressure of 13·3 atm. reflection overpressure. Curves *a* and *b*: before and until about 25 sec. after detonation, which occurred at arrow. Curves *c*–*f* were obtained 2, 3, 10 and 11 min., respectively, after detonation. *g* Shows the heavily damaged lungs of this animal.

whole day after the exposure. The picture also shows the very extensive haemorrhages in the lungs, especially in the left one.

Fig. 2 shows the changes in the frequency of the heart beats immediately after the detonation, which occurred at the heavy distortions in the electrocardiogram. The strong bradycardia is of rather short duration, but minor changes in the heart rate may persist for several minutes. Also in this case the shock wave pressure was high enough to affect the lungs seriously.

The blood pressure changes in a severe, lethal blast are seen in Fig. 3. Within 1 or 2 sec. after the detonation the blood pressure starts to drop. Usually it will increase again after 10–30 sec. This is also seen in this case, but the shock wave has been too violent, and after about 10 min. a fatal drop in the blood pressure is noticed. The lungs are very severely damaged.

Changes of the same kind as those just described in severe blast injury have been reported by a number of authors to occur after decompression if the rate of decompression is fast enough. Neither in blast nor in explosive decompression[11] has it been possible to establish any relationship between the presence or absence of extrasystoles or missed beats and the cardiac cycle phase in which the exposure occurred.

We have found[15,16] that the respiratory and circulatory changes in blast injury can be prevented if the animals have been bilaterally vagotomized and deprived of their vasopressor regulating mechanism by carotid sinus denervation before the exposure. Hitchcock and coworkers[13] have shown that the blood pressure drop caused by explosive decompression could be prevented in the same way, and Gelfan[9] found that atropinization of the animal before the decompression prevented the postdecompressive bradycardia. The circulatory changes after explosive decompression and after shock wave exposure, therefore, have been assumed to be of the same genesis, and it is generally believed that they, as well as the respiratory changes, are elicited by stimulation of vagal stretch receptors in the lungs, distended by the haemorrhages and traumatic emphysema, and mediated through pulmonary hæmodynamic reflexes.[13,19]

In a recent investigation[17] we have, however, found that the cause of the changes in cardiac activity in blast injury evidently is to be sought mainly in the direct damaging effect of the shock wave on the heart. In a large number of experiments we have been able to show that a strong shock wave may cause severe myocardial damage. This is clearly seen in Fig. 4. The electrocardiographic changes immediately after the detonation are those of the dying heart. Gradually there is, however, some recovery and after a short period of ventricular flutter starting about 8 sec. after the detonation and lasting for about 5 sec., the ECG pattern changes to a right bundle branch block type. This animal finally dies.

In explosive decompression, on the other hand, a direct mechanical effect on the heart seems to be of less

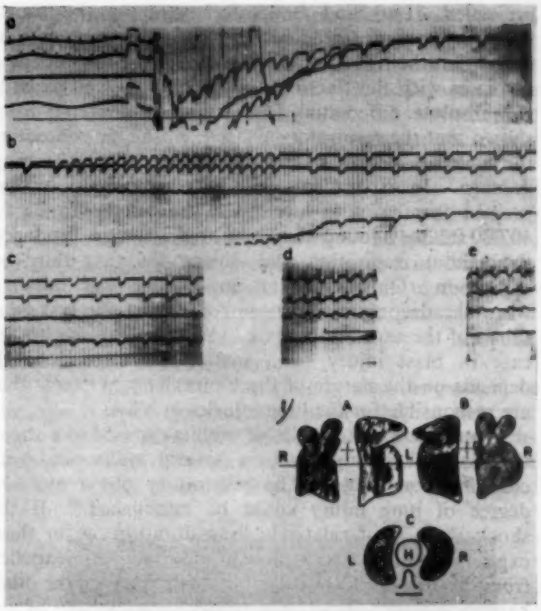

FIG. 4. Electrocardiogram of a rabbit exposed to a shock wave with a peak pressure of 20·9 atm. reflection overpressure. Curves *a* and *b*: before and until 18 sec. after the detonation, which occurred at the heavy distortion in the curves. *c*: 18 sec., *d*: 1·5 and *e*: 3·5 min. after detonation. *f*: Schematic drawing of lungs with haemorrhages.

importance. The short-lasting bradycardia in explosive decompression is rapidly succeeded by a very irregular heart rate due to the struggling induced by anoxia. As a consequence of the deranged haemodynamics caused by the shock wave effect on the heart, and the deteriorated pulmonary vascular bed, there is in blast also a strong decrease in cardiac output occurring almost immediately after the exposure to the shock wave.[20] Gelfan and Werner[11] have reported a decreased cardiac output in explosive decompression due to the combined effects of anoxia and mechanical interference with venous return.

In explosive decompression from atmospheric pressure to low pressure the respiratory and circulatory changes are also partly due to anoxia. The mechanical factors, however, seem to precede the anoxic ones in producing these changes. Also in blast injury, anoxia may play some part. As the ambient air pressure in blast, however, is rapidly restored to the predetonation conditions, anoxia in blast injury is a secondary phenomenon to the lung damage, and the immediate changes in respiration and circulation are of purely mechanical origin.

The degree of injury to the lungs in explosive decompression is dependent on the total pressure difference and the rate of establishment of the transthoracic pressure gradient, which in turn is a function of the decompression rate and of the condition of the respiratory air passages. With closed air passages the pressure equalization between the lung air and the ambient air is

prevented. Luft and Bancroft,[14] studying the transthoracic pressure gradient in rapid decompression, found that the transthoracic pressure in the human chest increases with the fractional differential as well as with the absolute differential. Berg and co-workers[21] have shown that the respiratory phase (*i.e.*, the air content of the lungs) is also of importance as regards the ensuing damage. In experiments with rats explosively decompressed from ground level to a simulated altitude of 40,000 ft., they found that lung injuries were produced throughout inspiration and during the first third of expiration. Only slight or no damage was inflicted when the decompression occurred during the last two-thirds of the expiratory phase. Whether this is also the case in blast injury, is a matter for discussion. It depends on the nature of the biomechanical events that are responsible for the lung injuries in blast.

In an experimental series of rabbits exposed to a shock wave of rather long duration (several milliseconds) no clear relation between the respiratory phase and the degree of lung injury could be established.[22] If the shock wave is of relatively long duration, as in these experiments, there is a certain amount of air expelled from the lungs. A short-lasting shock wave on the other hand was found to cause no significant expulsion of air. This is seen in Fig. 5, which shows the respiration curves of two rabbits. The upper curve is from an animal that was exposed to a shock wave of rather long duration generated in the detonation chamber. There is a strong expulsion of air caused by the high pressure phase of the detonation. The normal expiration should have occurred 0·2–0·3 sec. later. The lower curve is obtained from a rabbit exposed to a shock wave of very short duration. There is no sign of an expulsion of air from the lungs in this case. The degree of pulmonary injury in blast seems to have no relation to the possibility of expelling air from the lungs, as the damage is often more pronounced after exposure to a shock wave of longer duration than after exposure to a short-lasting one.

The differences between the effects of explosive decompression and of blast injury mentioned above may be explained, if the biomechanical genesis of the pulmonary injury is assumed to be different in these two conditions. In explosive decompression the lung damage may be caused by one or both of the two following mechanisms[23]: (*i*) the rapid expansion of the lungs may stretch the alveolar walls to the point of rupture; or (*ii*) the sudden increase of intrapulmonary pressure may force parts of the lung against the rigid thoracic wall. During the extremely rapid pulmonary expansion there is an increased intrapulmonary pressure, and thrust and shear forces will rupture the lung tissue.

Concerning blast injury, the idea originally presented by Zuckerman[24] is by now generally accepted, *viz.*, that the lung injury is due entirely to the impact of the shock wave on the chest wall and not to a shock wave

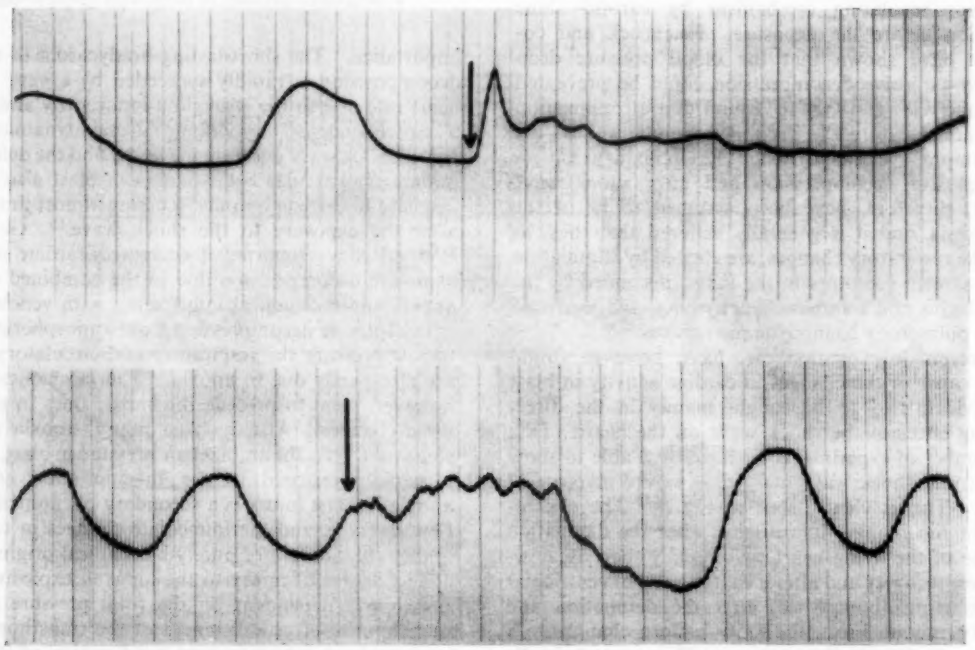

FIG. 5. Respiration curves of two rabbits exposed to shock waves. Upward deflection of curve is expiration. Detonation at arrow. *Upper curve:* Duration of entire overpressure phase of the shock wave about 30 millisec. Maximum reflection overpressure in the shock wave: 8·2 atm. *Lower curve:* Duration of overpressure phase of the shock wave about 1 millisec. Maximum reflection overpressure in the shock wave: 10·4 atm.

transmission through the upper respiratory passages down to the lungs. Furthermore, the lung damage in blast injury probably does not originate from a general over-expansion of the thorax, but probably from the local effects of inertia, spalling, and possibly also from implosion,[5] and acceleration or tearing forces will rupture the lung tissue.[25] If the shock wave is of long duration intrapulmonary pressure changes occur, but a very short-lasting blast wave will probably pass without causing a pressure increase simultaneously in the whole lungs.

In co-operation with Dr. Kolder from the Physiological Department of the University of Vienna, we have recently studied the transthoracic pressure differences in rabbits exposed to short-lasting shock waves in the detonation chamber. The goal of these experiments has been to try to determine whether the pressure changes occurring inside the thorax are not coincident in time with the external shock pressure variation, indicating the occurrence of volume changes in the lungs.

A barium titanate pressure transducer was inserted into the thoracic part of the œsophagus and another pressure transducer was fixed externally to the chest wall at exactly the same level. In addition to the external shock wave pressure and the intrathoracic pressure variations, the difference between these two pressures was recorded by differential connection of the transducers.

The results of such an experiment are shown in Fig. 6. *Curve a* is the pressure outside, *i.e.*, in the incident shock wave. *Curve b* is the pressure recorded in the intrathoracic part of the œsophagus. Owing to the differential coupling of the transducers, this pressure curve has a direction opposite to that in *curve a*. Finally, *Curve c* is the difference curve.

It was found in these experiments that the peak blast pressure outside the thorax is always higher than the peak pressure recorded inside the thorax. The high-pressure phase is of somewhat longer duration inside the thorax. There is also a time lag of about 0·7 millisec.

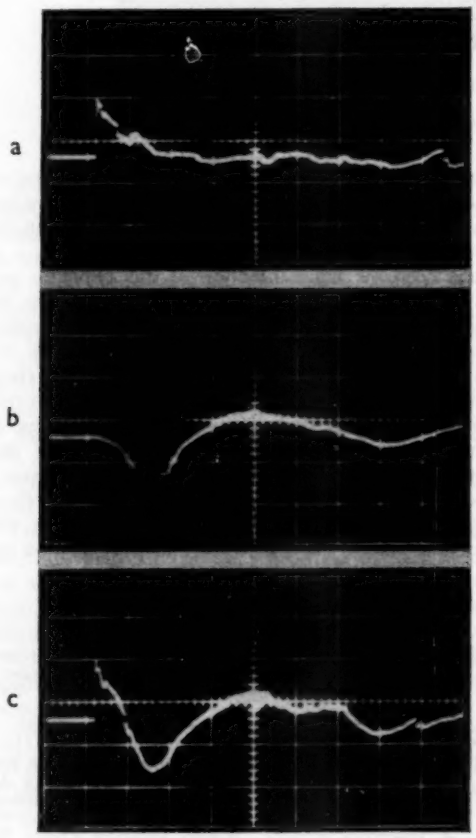

FIG. 6.

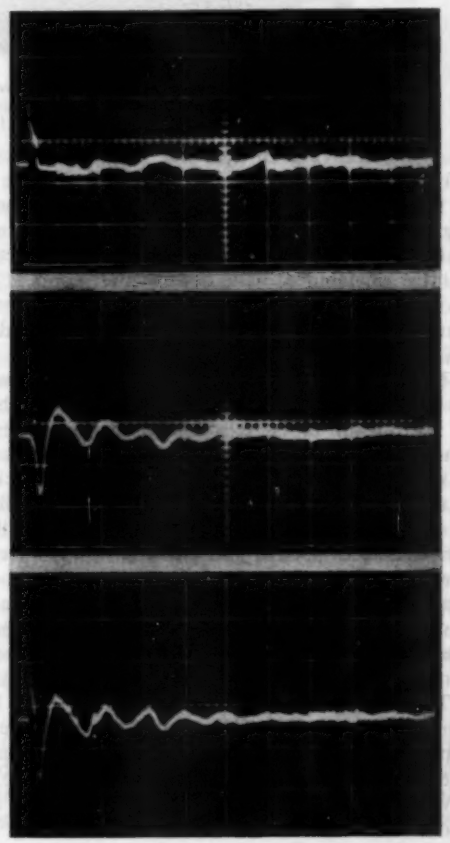

FIG. 7.

FIGS. 6–7. Shock wave recordings from two blast experiments. *a*. Incident air shock wave. *b*. Pressure wave in the intrathoracic part of the œsophagus of the rabbit. *c*. Curve of difference between external shock pressure and intrathoracic pressure. Time between two vertical lines: 1 millisec. (Fig. 6); 5 millisec. (Fig. 7). Pressure, between two horizontal lines: ∿0·8 atm.

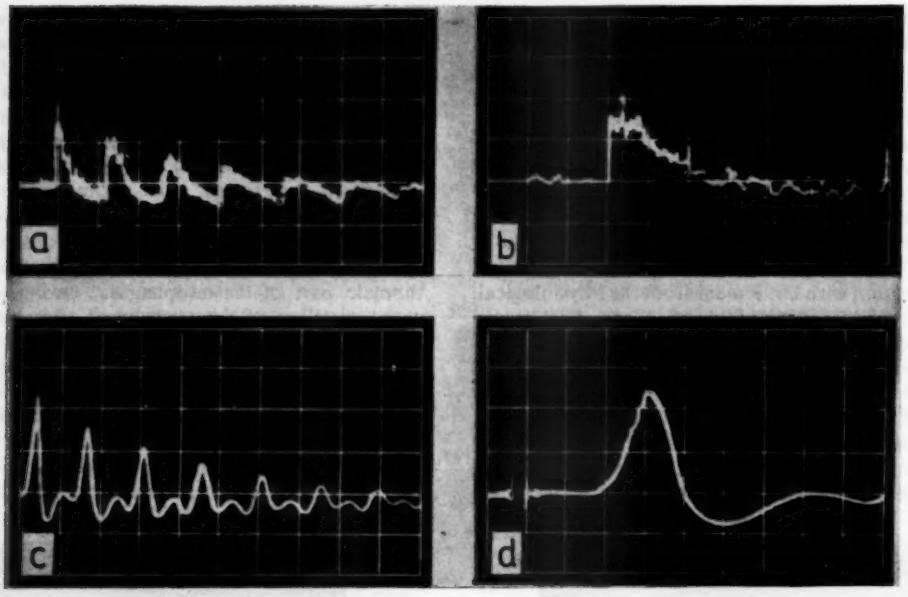

FIG. 8. Recordings of intrathoracic pressure pattern in a blast experiment with a rabbit. *a* and *b*: Incident air shock wave. *c* and *d*: Pressure curves obtained in the thorax cavity turned away from the charge. *a* and *c*: 5 millisec., *b* and *d*: 1 millisec. Pressure (between horizontal lines): 0·35 atm. in all curves.

between the attainment of a pressure inside the thorax as high as outside. Fig. 7 shows the same event as in Fig. 6, but the time axis is 5 millisec. instead of 1 millisec. This figure shows that the shock exposure causes a number of damped oscillations in the thorax (*Curves b* and *c*) which have no equivalent in the incident shock wave (*Curve a*). The frequency of these rapidly subsiding oscillations is about 200 c./sec.

The differential pressure measurements showed that the increase of the inside pressure starts earlier than that of the outside pressure, although the peak pressure is reached later intrathoracically. This difference is due to different velocities of propagation of the shock waves in the outside air and in the body. The ascending part of the intrathoracic pressure curve is less steep than the corresponding part of the incident shock wave. This breaking of the steep shock front, as well as the lower peak pressure inside the thorax, is mainly due to the damping properties of the thoracic tissues, the lungs (being composed of parts with large differences in acoustic impedance) certainly playing the greatest role.

These damping properties of the thorax and lungs is illustrated in Fig. 8. These curves were recorded in an experiment in which a barium titanate transducer had been inserted through the thoracic wall into the pleural cavity of a rabbit. The animal was exposed to a shock wave with the other side of the thorax facing the explosive charge. The two upper curves show the incident shock wave with, in *Curve a*, the sequence of shock peaks with diminishing amplitude produced in the closed detonation chamber. *Curve b* shows the first of these pressure peaks. *Curves c* and *d* show the corresponding pressure pattern inside the thorax. The shock wave has been damped, and all the smaller oscillations seen in the incident wave are completely lacking here.

It has been the main intention of this paper to call attention to some similarities and dissimilarities in the biological effects caused by explosive decompression and by blast. In spite of the great similarities in the pathological and pathophysiological end results of these two kinds of trauma, dissimilarities probably exist, especially as far as their biophysical mechanisms of occurrence are concerned. In order to verify this assumption more experiments are, however, necessary, comprising a correlation of the physiological effects with a study of the structural changes in the lungs, not only on the macro- and micro- but possibly also on the ultra- and molecular structure levels.[18]

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SOME CONSEQUENCES OF WEIGHTLESSNESS AND ARTIFICIAL WEIGHT*

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(Communication from the National Aeromedical Centre, Netherlands)

ABSTRACT

Physiological consequences of weightlessness are discussed. Artificial ventilation will be necessary, because of the absence of convection. In the absence of gravitational clues to position, some disorientation may occur and motor activities may have to be relearned, but muscular atrophy is not likely to be a real hazard. It would be unwise to extrapolate from what is experienced during parabolic flights to what can be expected during semipermanent weightlessness.

Problems raised by rotation of the space vehicle to produce artificial "weight" are also considered, and it is shown that von Braun's proposal for the rotation of a 40 m.-radius satellite at an angular velocity of ^{2} radian/sec. is not fully satisfactory physiologically.

I. WEIGHTLESSNESS

WHEN discussing weightlessness and artificial weight I envisage these modalities in their semipermanent fashion as occurring in spaceflight and not the short-duration parabolic flights which in several respects are not at all comparable to our present problem. Spaceflight is not necessarily weightless, and it might be argued that in *powered* spaceflight (with ionic or photonic propulsion systems) rocket acceleration could be a good substitute for gravitational acceleration. Such powered spaceflight is, however, only a far distant possibility. It seems pretty certain that the first step in spaceflight will be the placing of a manned satellite in its orbit in order to continue its inertial (= weightless = Keplerian) flight permanently or semipermanently.

The very first step in spaceflight, the *conditio sine qua non*, thus proves to be the realization of weightlessness. All other factors distinguishing spaceflight from air flight, like temperature and radiation, are only secondary, although very important, points of consideration.

Now, what are the physiological consequences of weightlessness? I will try to enumerate them and discuss them briefly.

(1) *Air circulation*, needed for temperature regulation and respiration, will no longer be induced by convection. A very good ventilating system will have to take its place.

(2) *Body perception* will lack its gravitational clues. It has been argued that this will lead to a serious, embarrassing disorientation. Arms and legs would be floating in a virtually unknown and consequently uncontrolled manner; attached to the body they would be no longer its faithful tools. Man would have to look around to find the whereabouts of his arms and legs.

I do not believe, however, that this pessimism is warranted. It is true that gravity-induced traction and pressure no longer exist within the body, but traction and pressure are still occasioned by the interplay between flexor and extensor muscles, giving rise to an influx of proprioceptive information. The situation does not seem to me to be unlike the state of immersion in water. The differences in specific gravity between object and medium are, also in that instance, nearly cancelled out. And yet, lying in his bath, man will know whether his foot is extended or his toe is flexed. Or, again, the situation might be compared with the judgement of gaze direction when the eyelids are closed. Such judgement can be correct although the intraorbital tissues, practically similar in specific weight, do not furnish a graviceptive clue.

(3) *Motion and Locomotion.* All muscular activity intended to move an object will have to be re-learned. It requires great wariness and adroitness. Eating and drinking seem particularly difficult. Locomotion will

* Paper presented at the Space Medicine Symposium, 16–17 October, 1958.

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be equally annoyingly hampered by the "unnatural" mechanical pattern. Leaping from the floor will inevitably end in hitting the ceiling. It seems wise, therefore, to protect the weightless occupant from collision trauma by covering walls, floors and other surfaces with a resilient material and make edges of tables, chairs, etc., smooth and rounded.

Muscular atrophy is a feared consequence of weightless life—atrophy from inactivity. I do not believe that this is a real hazard. For one thing, there is no inactivity and it does not seem impossible that the execution of delicate movements elicits contractions in the antagonistic muscle-groups that are just as strong, though differently patterned, as when occurring under normal weight. Secondly, the vitally most important muscles of respiration and circulation remain practically uninfluenced by the cancellation of weight. Thirdly, if an optimal muscular activity is still not reached, there is no reason why such activity should not be pursued by means of some appropriate exercise (such as dummy rowing).

(4) A final question concerns the sensation of being weightless. The experiments with parabolic flights by Gerathewohl have shown large individual differences: sensations of floating, tumbling, falling, lift, standing on the head, rolling over, being suspended in an inverted position, etc., were noticed. The otoliths will doubtless be co-instrumental in causing these effects. Responsive to linear accelerations, they will register a zero value as the resulting vector of gravitational and centrifugal acceleration. The evoked neural response in the vestibular nerve will pass this information on to the cortex. The apperception—the central interpretation—proves, however, to be capricious, as might have been expected. The integrating characteristics (the time-constant) of the otolith-macula system and the adaptation-characteristics of the neural response in vestibular nerve and central pathways are consistent with a correct recording of "naturally" occurring (*i.e.*, short-lasting) accelerations. These are, in the peripheral and central system, integrated into velocities and, again, into distances. For instance, there is no disorientation while jumping with closed eyes. I mention jumping because it shows that the upward and downward phases are both correctly appreciated although the otoliths are—relative to their maculae—*throughout* in a zero-gravity state. It shows also that a zero-gravity state is not, as might be thought, automatically interpreted as "free-fall." It just depends upon the immediately preceding g-value imposed upon the otoliths.

The chaotic sensations experienced during the "weightless" parabolic flight-procedures are due to several factors: (1) the relatively long period of weightlessness (up to 30 sec.), (2) the complicated way in which it is produced—pull-up after a sharp dive.

It remains a little hazardous to extrapolate from what is experienced during parabolic flights to what can be expected during semipermanent weightlessness in space-flight. However, I feel confident in predicting that there will not be a sensation of falling if only because there is no way to sense in what direction falling should occur.

II. ARTIFICIAL WEIGHT

To parry the difficulties of weightlessness, the reintroduction of weight in the manned satellite has been proposed. This artificial "weight" can be readily obtained by making the satellite rotate around its own axis. The concept of von Braun is well known: a wheel with a radius of 40 m. will rotate around its axis with an angular velocity of $\frac{2}{7}$ radian/sec. (Fig. 1). The resulting centrifugal acceleration ($\omega^2 r$) will be $\frac{1}{4}\,g$. The solution, simple as it seems, raises, however, several new problems, of which I will mention:

(*a*) "Free-falling" objects will—relative to an inertial system outside the satellite—pursue a straight path, determined by the tangential velocity at the moment of free-falling (Fig. 2). Viewed by an observer within the satellite, the path will not coincide with the vertical. The object "falls" in a curvilinear fashion.

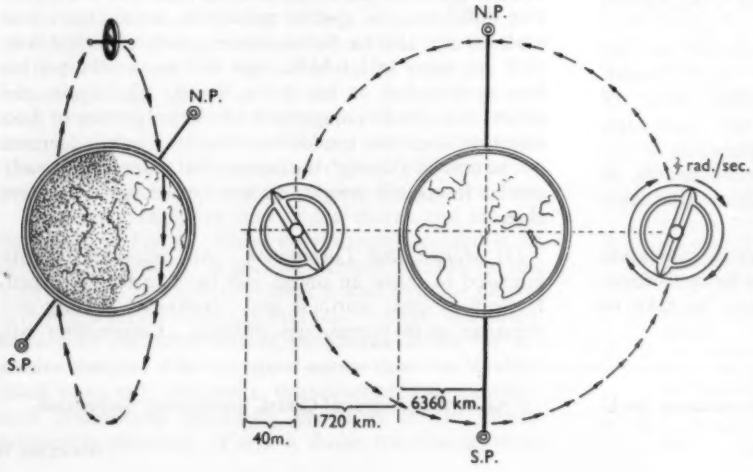

FIG. 1. Schematic representation of Wernher von Braun's concept of a spacestation, with a 2-hr. orbit. The orbit would coincide with the Earth's terminator (the great circle dividing the Earth into its sunlit and dark hemispheres). The spacestation would rotate around its own axis with an angular velocity of $\frac{2}{7}$ radians/sec.

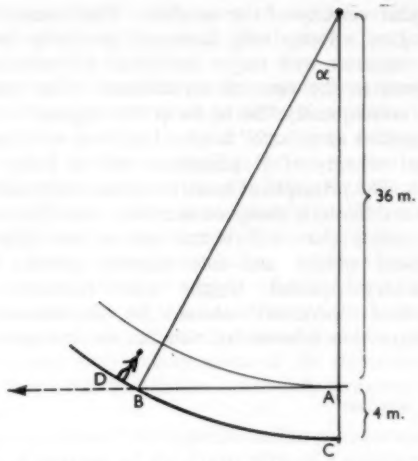

FIG. 2. The course $A \rightarrow B$ of a "freely-falling" object in the spacestation. When the object hits the floor at B, the point C has reached D. Viewed by an observer in the station the object falls in a non-perpendicular fashion behind its "natural" target.

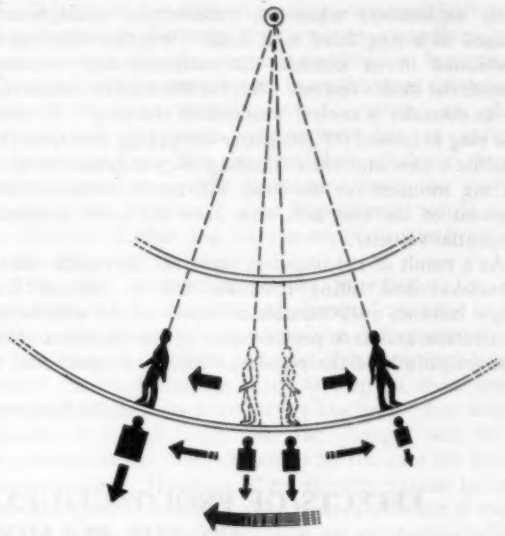

FIG. 3. "Weight" changes occasioned by walking in the spacestation. Following the direction of rotation the "weight" will increase; conversely, it will decrease when proceeding in the opposite direction.

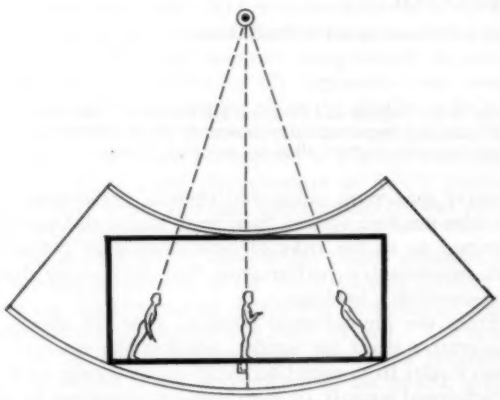

FIG. 4. Schematic representation of changes in posture according to changes in position on a flat-floored room. When changing from one position to another, the satellist will experience conflicting sensory information from visual, graviceptive and semicircular canal clues.

FIG. 5. Life on board the spacestation. Two members of the crew are discussing their problems; a third has just turned away, and rotating around his longitudinal axis is taken by surprise by a "false" tilting sensation and tilting reaction.

(*b*) An occupant of the satellite will experience weight-changes when moving to and fro. Following the satellite's direction of rotation the "weight" will increase; conversely, walking in the opposite direction the "weight" will decrease (Fig. 3). We may now compute the walking speed necessary to double or halve one's "weight." To this end, the absolute tangential velocity should be multiplied or divided respectively by $\sqrt{2}$, since the centripetal acceleration is proportional to the square of the tangential velocity. The satellite's tangential velocity is known from the given values for angular velocity and radius ($V = \omega r = \frac{2}{7} \times 40$m./sec. $= 41$ km./hr.). The walking speed must consequently be respectively $(41\sqrt{2} - 41) = 17$ km./hr. following the satellite's direction, or $(41 - 41/\sqrt{2}) = 12$ km./hr. counter to the satellite's direction.

(*c*) Walking within the satellite, the satellist will experience progressive changes in body-position; in this experience the visual, graviceptive and semicircular sensory information are mutually conflicting (Fig. 4). These conflicts will arise both when the floor of the satellite's room is kept flat or when it follows the outer curvature.

(*d*) Rotations of the head occurring around an axis not parallel with the axis of the satellite will provoke "false" impulses in the semicircular canals (Fig. 5).

Although a full quantitative analysis of the phenomenon requires some mathematics, the principle can be

easily understood when the semicircular canal is envisaged as a ring filled with fluid. Whether the ring is positioned in or outside the satellite's axis remains immaterial in this respect. So, for the sake of simplicity, let us consider a central position of the ring. If, next, this ring is turned 90°, its plane coinciding first with the satellite's axis and then standing perpendicular to it, a driving moment on the fluid will result because every segment of the ring will now have the same maximal tangential velocity.

As a result of the impulses upon the labyrinth, tilting sensations and tilting reactions will be elicited that might have an unfavourable influence on the well-being, motivation and task performance of the space-traveller. The magnitude of the physical effects is proportional to the angular velocity of the satellite. The extent of the physiological effects, will, however, probably bear a critical character with major individual differences, just as happens in the case of sea-sickness. The solution should, consequently, be to keep the angular velocity of the satellite at a "safe" level. I am not sure that the proposed velocity of $\frac{2}{7}$ radian/sec. will be fully satisfactory. The principle of human engineering might well prompt a differently designed satellite, a satellite with a longer radius that will better answer the exigencies of optimal weight and safe rotation speed. These two factors—optimal weight and freedom from labyrinthine "pericula"—should be incorporated in the construction schemes of vehicles for interplanetary flight.

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EFFECTS OF PROLONGED EXPOSURE TO POSITIVE *g* LOADINGS ON THE PULMONARY GAS EXCHANGE*

By HILDING BJURSTEDT,† M.D.

(Communication from the Laboratory of Aviation and Naval Medicine, Stockholm)

ABSTRACT

The results of subjecting anaesthetized dogs to prolonged *g* forces in the head-to-tail direction are reported. In spite of the fact that the animals were hyperventilating and breathing 100% oxygen, hyperoxaemia was found; this is attributed to disturbances of ventilation and perfusion in the lungs. It was not clear why marked alkalosis was also present.

It is neither possible nor desirable to fix a border-line between aviation medicine and space medicine. This is well borne out by the multitude of medical acceleration problems now facing us, which are common to both areas of research. One such problem of paramount importance concerns the means necessary to preserve human performance under abnormal *g* loadings.

The time during which the occupants of a space vehicle will be exposed to varying levels of increased gravitational stress may be prolonged over several minutes. Thus, with a continuous linear acceleration of 3 *g*, over 9 min. exposure would be required if escape velocity is to be reached. The same velocity would be achieved if 30 *g* were allowed to act for 44 sec. The first alternative would be very unsatisfactory from the point of view of propellent requirements; the second is physiologically not possible. Any attempt to strike a happy mean for reaching escape velocity would thus require an average *g* loading in excess of 3 *g* and a total exposure time that would probably amount to several minutes.

If, during such exposures, occupants are to participate in the control of the vehicle, and especially if it is deemed profitable to make use of man's special assets in order to preserve maximum safety and optimal performance of the man-machine system, then more knowledge must be obtained as to the risks of deterioration of judgment and psychomotor performance that may result from long-duration *g* loadings.

From the physiological point of view the effects of accelerative stress are similar, whether the stress ($g \times$ time) results from radial acceleration, as during turns in a high-speed aircraft, or from linear acceleration, as in a space vehicle picking up speed to attain escape velocity. Because the high speeds and manoeuvrability of certain present-day aircraft allow radial *g* loadings of very long duration, man is, in fact, already struggling with much the same ($g \times$ time) stresses as may have to be coped with in the launching of space vehicles.

The experiments reported here are strictly limited to the physiological area. However, they were designed to enable a study of certain physiological responses to *g*, which might require several minutes to develop before they would cause interference with psychomotor performance or functions of the central nervous system in general. It was thought that such slow-developing responses might have been missed entirely in the relatively short-lasting runs (15–60 sec.) in human

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centrifuges; from which most of our knowledge as to physiological reactions and psychomotor performance is derived.

Exploratory experiments were made on anaesthetized dogs. The human centrifuge at the Karolinska Institute was used to produce positive *g* loadings (acting in the head-to-tail direction), lasting for up to five minutes. Interest was focused on the possibility that the accelerative force might cause derangements in the pulmonary circulation and so interfere with the oxygenation of the blood passing through the lungs. It was thought that the increased effective weight of the blood, in combination with the high distensibility of the lung vessels, in the main devoid of external tissue-(counter-)pressure, might cause such engorgement of the dependent parts of the lungs that ventilation is seriously impaired in these regions.

The experiments were performed in collaboration with Dr. J. Coleridge of the University of Leeds and P.-O. Barr. Recordings were made continuously of the arterial oxygen saturation and *p*H, the latter serving as an index of the arterial p_{CO_2}.

The main results from these experiments on anaesthetized dogs were that: (1) low-to-moderate *g* forces produced an initial apnea followed by a marked hyperventilation, the latter response being caused by carotid chemoreceptor excitation, (2) exposures over several minutes shifted the arterial *p*H to the alkaline side by up to four-tenths of a *p*H unit during the course of the runs, a change that would correspond to a severe lowering of the arterial p_{CO_2}, and (3) exposures as in (2) produced severe hypoxemia although hyperventilation was present and 100% oxygen was breathed.

The last-mentioned observation clearly indicates that a substantial amount of the blood flowing through the lungs is not oxygenated despite the concomitant hyperventilation and inhalation of 100% oxygen. The venous admixture was sufficiently large to cause a progressive net reduction in the oxygenation of the mixed, arterial blood to around 80% saturation. Since the animals were hyperventilating on 100% oxygen, this must imply a great alveolar-arterial oxygen difference and, accordingly, the development of a very large pulmonary shunt.

These results demonstrate that the pulmonary circulation may not function according to the needs of the body during increased gravitational stress, and that prolonged exposures may indeed precipitate changes in the uptake of oxygen and removal of carbon dioxide. Prolonged *g* loadings are thus capable of causing ventilation/perfusion disturbances in the lungs giving rise to a condition that may conveniently be termed *acceleration hypoxemia*. This kind of hypoxemia would exert the same deleterious effects on the central nervous system as does high-altitude hypoxemia, although it has an entirely different origin. The concomitant alkalosis (hypocapnia) may be equally deleterious from the performance point of view, since hypocapnia would tend to decrease further the oxygen supply to the brain *via* vasoconstriction.

Thus, the importance of the time-factor for the development of critical blood chemical changes in the body under abnormal *g* loadings was demonstrated.

It remains to be seen, whether the above-mentioned blood chemical changes also develop in man under prolonged exposures to positive *g* loadings. For several reasons it is not likely that the changes will be as impressive as has been shown to be the case for anaesthetized dogs. However, there is every reason to look into the matter, especially since both in aviation of today and in space travel of tomorrow we are dealing with *g* levels that are considerably higher than those used in the animal experiments just described. We are therefore currently engaged in similar experiments on human subjects.

Some final comments seem justified in this connection. There is a definite and immediate need to determine the extent to which deterioration of judgment and psychomotor performance may be caused by prolonged exposures to sub-blackout *g* levels. Information in this respect can be obtained with the aid of human centrifuges by employing suitable experimental designs worked out by experts in experimental psychology. However, from the results just presented it is tempting to make a case for a combined, psycho-physiological approach to performance problems resulting from ($g \times$ time) stresses or from other environmental stress factors. On the one hand, once a deterioration of performance has been detected by psychological methods, the question immediately arises as to the physiological basis for the observed change: a better knowledge of intervening physiological mechanisms would make it much easier to predict the circumstances under which performance deterioration is prone to develop. On the other hand, any attempt to alleviate or counteract such deterioration amounts to groping in the dark if its physiological background is insufficiently known or neglected.

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THE PHYSIOLOGICAL EFFECTS OF TRANSIENT MECHANICAL FORCES: A REVIEW OF THEIR RELEVANCE TO ASTRONAUTICS*

By Flt. Lt. J. C. GUIGNARD,† M.B., Ch.B., Fellow
(Communication from the R.A.F. Institute of Aviation Medicine)

ABSTRACT

Mechanical stresses which may occur in spaceflight and the physiological responses to these stresses are reviewed. Noise and vibration levels are high in large rocket vehicles under power. During re-entry at orbital velocities buffeting of a space vehicle would be poorly damped at the fringe of the atmosphere and might induce vibrations and oscillatory flight patterns of sufficient intensity to prohibit the crew from controlling the descent. In space there would be no damping and any vibration must be absorbed by the vehicle and its occupants. Structure-borne oscillations at frequencies below 100 cycles/sec. are a potential cause of discomfort, fatigue and impaired performance; and low-frequency shaking, below 10 cycles/sec., is a serious nuisance and is difficult to isolate.

It is considered doubtful whether man could undertake operations in individual spacesuits outside the main vehicle when in orbit. The suit would have to be a massive device incorporating gyroscopic stabilization to prevent undamped spin or tumble, and whole-body harness and anti-shock packaging to avoid impact injuries in a collision.

I. INTRODUCTION

AVIATION physiologists have naturally devoted much attention to the effects of prolonged accelerations on man. In flight, the most important actions of *g* forces of long duration (*i.e.*, lasting more than one second) are three:

(1) mechanical interference with voluntary and vegetative muscular activity,

(2) circulatory embarrassment, including loss of vision and consciousness, and

(3) neurophysiological disturbances, including disorientation of vestibular origin.

Although the rocket engineers say that in order to achieve orbital or escape velocity with reasonable economy the astronaut will be exposed to multiples of *g* lasting several minutes, all the evidence suggests that the acceleration patterns of take-off should be acceptable. Suitably aligned with respect to the thrust, the man would remain conscious and able to play some part in the control of the vehicle, should he be required to do so. However, force arising from the acceleration of take-off is not the only force to which he will be exposed.

II. MECHANICAL STRESSES WHICH MAY OCCUR IN SPACEFLIGHT

Transient and fluctuating forces will affect the man during ascent, during re-entry and, presumably, during certain operations in space. Evidence so far revealed indicates that high levels of noise and vibration occur in large rocket vehicles while under power. In addition, the acceleration pattern of multi-stage machines is itself inconstant, being characterized by peaks and decays of acceleration—culminating in the transition to free fall. The dog in the Russian *Sputnik II* is said to have taken three times longer to settle down physiologically after its ascent into orbit than it took after centrifuge simulation of the same acceleration pattern on the ground.[1] The additional factors, supposedly, were noise, vibration and subsequent weightlessness.

In true ballistic spaceflight, the man will be weightless but not immune from mechanical disturbance. It is unlikely that, in any space vehicles we can reasonably foresee, the crew would spend much time floating freely in a spacious cabin. They will rather remain strapped in their seats, constrained to the structure of the vehicle and, therefore, exposed to any shocks or vibrations transmitted by it. Noise and vibration isolation of the occupants is already an important problem in existing aircraft. It may be expected to be a serious one in space vehicles containing noise and vibration sources in the form of ancillary equipment. Such sources will be transferring vibratory energy to a structure which, in free fall and *in vacuo*, is devoid of external damping. Vibrations in certain frequency ranges (particularly low-frequency oscillations in the range 1–100 cycles/sec.) are known to impair human comfort and efficiency. It is possible that their effects may be potentiated by other physiological stresses (such as weightlessness) which will occur in space vehicles.

It is often imagined that men will undertake operations in individual spacesuits outside the main vehicle while in orbit. If this is ever possible or necessary, it may be anticipated that the orbital duty survival suit (or capsule) will—for numerous logistic reasons—be an elaborate and massive affair. The chances of disaster attending attempts at free flight by men in space using personal propulsion systems are alarming in prospect. The main foreseeable hazards, as far as this review is concerned, are: (1) undamped spin or tumble resulting from eccentric propulsive thrust or glancing collision, and (2) impact injury to the man inside the canister, should it collide with another mass. The physiological effects of rotation are disorientation, sickness and, at high rates

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of spin about short axes of the body, circulatory embarrassment due to centrifugation.[2] Any of these effects may prejudice survival in a spacesuit. Briefly, the solution to (1) may demand gyroscopic stabilization of the capsule, and that to (2), whole-body harness and anti-shock packaging of the man inside the suit as well as, perhaps, complete control of his extra-mural activities from the parent vehicle.

Re-entry is the final situation in which the man will be exposed to severe forces. Theoretical computations suggest that the deceleration pattern of a re-entrant vehicle using aerodynamic braking could be kept within physiological limits. It is likely that the first approach to the manned re-entry problem will be made using aircraft-like vehicles* which revert from ballistic to man-controlled aeroplane flight during the descent. The success of such ventures and, indeed, the contribution to control which can be expected of the pilot, will depend upon a better knowledge of the behaviour of the atmosphere at altitudes above 100,000 to 150,000 ft. In spite of research carried out under the sponsorship of the I.G.Y. and military programmes, information on the meteorological activity of the upper atmosphere is still relatively scanty—or at least not generally revealed. If, for example, there are significant turbulent fluctuations in the density and velocity of the air at extreme altitudes then, although the air is very thin, vehicles penetrating the atmosphere at orbital velocities might be subjected to a form of buffeting. Because the air is very thin, gyrations or vibrations induced by such disturbances would be very poorly damped. If severe vibrations and oscillatory flight patterns were induced during the earlier stages of re-entry then the difficulties of a man-controlled descent would be great and, perhaps, prohibitive.

A special problem will be to decide whether space vehicles will, in general, offer assisted-escape systems. If they do—and it is probable that the first generation of ballistic aircraft will—it is reasonable to suppose that the escape systems will be direct developments of current ejection devices, with a very high altitude capability. It may be argued that survivable emergencies are most likely to arise during the earlier stages of ascent or the later stages of re-entry, so that the requirements would not be far removed from those of present-day high performance aircraft.

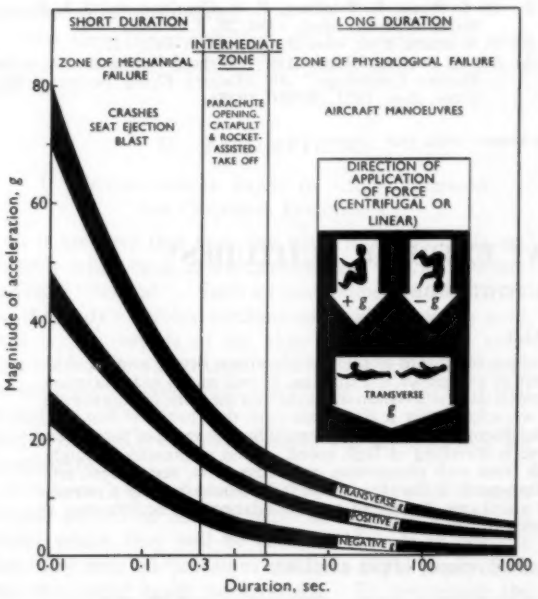

FIG. 1. Limits of human tolerance to acceleration. Mean tolerable acceleration levels (for sustained "centrifugal" or linear forces) are plotted against duration of application. The parameter is direction of application. Some important causes of long and short duration acceleration in aviation are indicated under each zone.

III. PHYSIOLOGICAL RESPONSES TO MECHANICAL FORCE

The parameters of human tolerance to linear acceleration have been summarized in Fig. 1 and responses to vibration as a function of frequency in Fig. 2. Fig. 1 shows that the limits of anatomical and physiological tolerance to linear acceleration can be plotted in the form

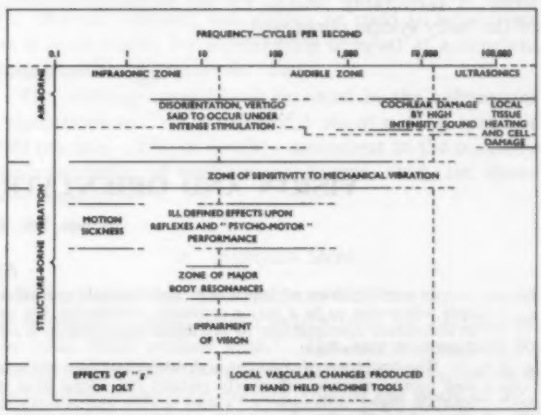

FIG. 2. Some effects of vibration on man. The horizontal double lines indicate the frequency ranges over which these effects have been reported. Hatched lines indicate uncertain limits. The distinction between air-borne and structure-borne vibration is somewhat arbitrary in that, once vibratory energy has entered the body, its effects are generally the same—whether it reached the body through the air or through a solid structure. However, some phenomena are particularly associated with air-borne noise and others with mechanical vibration. This chart presents the effects solely as functions of frequency, although any particular manifestation must also depend upon the amplitude, direction of application and duration of the stimulus.

* Such as the X-15 high-altitude research aircraft.

of strength/duration curves. This presentation illustrates three main points: that tolerance is largely determined by the direction of application of the force with respect to the long axis of the body; that low levels of acceleration greater than 1 *g* can be sustained indefinitely; and that very high levels can be applied for short periods without injury or physiological embarrassment. Not indicated in Fig. 1 is the fact that the time-course of a force applied to the body matters in addition to its peak value and absolute duration. It can be shown, for example, that if the thrust of an ejection-seat is built up too quickly in relation to the natural period of oscillation of the man-seat system, then there occurs in the body amplification of acceleration, which may be injurious.[3]

Analogous phenomena may be observed during impulsive physiological stresses. It was found in studies of visual blackout under positive acceleration that, if this is applied too quickly, cardio-vascular compensation lags behind the stimulus.[4] For example, subjects submitted to $+3\,g$ at a rate of application of $3{\cdot}6\,g$/sec.—the maximum possible on our centrifuge—frequently reported transient grey-out followed by a subsequent clearing of vision (while still at $3\,g$) with a latency of several seconds. The same subjects taken to $3\,g$ at a slow rate of onset—$0{\cdot}1\,g$/sec.—suffered no grey-out, while arterial pressure recordings confirmed that circulatory response followed the development of the stimulus. This is a physiological example of tolerance being augmented when the rate of application of the stress is favourably related to the frequency-response of the body system concerned.

Fig. 2 summarizes human reactions to vibration in terms of frequency. Structure-borne oscillations at frequencies below ~ 100 cycles/sec. are a potential cause of discomfort, fatigue and impaired performance in spaceflight as well as in conventional aviation. At frequencies above, say, 20 cycles/sec., mechanical vibration is increasingly well attenuated by the body and isolation is comparatively easy. Low-frequency shaking, especially in the range below 10 cycles/sec., can be very disturbing and may be a serious nuisance, as it is difficult to isolate.

In conclusion, research into the physiology of acceleration may have many applications to astronautics. The acceptable acceleration and deceleration patterns of ascent and re-entry will be largely determined by physiological considerations. As far as transient forces are concerned, the physiologist can advise on the necessity for shock and vibration isolation of the man in the vehicle—in the light of our knowledge of the dynamic and neurophysiological responses of the body to impact and oscillation.

ACKNOWLEDGEMENT

Acknowledgement is made to the Director-General of Medical Services, Royal Air Force, for permission to publish the paper.

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VISION AND ORIENTATION AT EXTREME ALTITUDES*

By Sqn. Ldr. T. C. D. WHITESIDE†

ABSTRACT

In some phases of spaceflight and ballistic aeronautics in which significant angular accelerations occur, motion sickness will prove to be a major problem. However, the importance of experience and training, as well as the wide variation in individual susceptibility to vestibular stimulation, is already appreciated in aviation medicine and the same factors should operate in spaceflight.

The problems of vision at high speed and high altitude are also discussed. The limitations of human speed of perception and motor reaction effectively restrict the visual field when one is travelling at high speed. Even in present-day high-altitude flight, difficulties of visual search and orientation result from such phenomena as intense glare, remoteness, and depression of the horizon, and in the absence of a definite fixation-point in the view ahead there would develop a physiological "empty-field myopia" (in which the eye tends to exert about one dioptre of accommodation). The inference is that the unaided eye will be of little use in space, either for search or for navigation.

It is regretted that the full text of this paper is not available

* Paper presented at the Space Medicine Symposium, 16-17 October, 1958.

† R.A.F. Institute of Aviation Medicine, Farnborough, Hampshire.

MAN'S THERMAL ENVIRONMENT DURING INTERPLANETARY TRAVEL*

By Flt. Lt. J. BILLINGHAM,† B.M., B.Ch., M.A.

(Communication from the R.A.F. Institute of Aviation Medicine)

ABSTRACT

The various factors affecting heat exchange between man and a sealed cabin are considered. Probable values for the various parameters are assumed and calculations made of the heat transfer under ten different conditions. These results have been used as the basis for a specification for environmental conditions during routine interplanetary flight.

I. INTRODUCTION

THIS paper considers the factors affecting heat exchange between man and the sealed cabin at various times during interplanetary travel. It deals with the requirements for the physical characteristics of the cabin environment under normal conditions and gives some indication of how man can be protected against extremes of thermal stress in an emergency.

In making these calculations, several assumptions have had to be made. One reason for this is the lack of knowledge of the final design of the first space vehicle to make prolonged flights. Consequently it is necessary to consider heat exchange under a variety of possible conditions, any one of which may be realized in the future. Even with such knowledge, however, we still lack some of the essential data required for calculations of heat flow; for example, heat flow through clothing under conditions of zero gravity.

First, then, the assumptions will be considered in some detail, as it is on them that the subsequent calculations are based.

II. ASSUMPTIONS

1. PHYSIOLOGICAL STATE OF CREW MEMBERS FOR OPTIMUM EFFICIENCY

It is assumed that man will work most efficiently and happily when he is in an environment which is physiologically "neutral." Such an environment does not call on the body's defence mechanisms against heat or cold, that is, the vessels of his skin will be neither vasoconstricted nor vasodilated, and he will not be shivering or sweating. Under such conditions, and with air that is neither too wet nor too dry, and with a wind velocity that is not too great, most people will say that they are comfortable.

I believe it to be essential that the crew of a space vehicle should be able to select at any time conditions under which they will be comfortable. It is possible that they may on occasions welcome slight discomfort, but this could easily be arranged. To appreciate the distracting effects of cabin environments which depart more than a few degrees from the comfort zone, when not required so to do, reference should be made to Simons' article[1] on his high-altitude balloon flight.

At the present time, "comfort" is not capable of complete analysis. It offers a fruitful field for research, particularly in its relation to performance at mental tasks, and to human behaviour and attitude; and both of these will be of cardinal importance during interplanetary travel. For the purposes of this paper man is assumed[2] to be comfortable with a mean skin temperature of 33·5° C.

2. CLOTHING

During routine interplanetary flight, man will probably wear clothes, for the following reasons: protection against superficial injuries; protection against burns which are a hazard in an oxygen-rich atmosphere; convention; and for the attachment of apparatus and carrying things in pockets. Clothing is not necessary for thermal comfort, but it may be used to advantage, as it is on Earth, for maintaining comfort at a constant level at different metabolic rates.

The clothing assembly is assumed in the subsequent calculations to have a value of 1 clo at a wind speed of 100 cm./sec. This is roughly equivalent to the ordinary male ensemble of medium-weight suit, shirt, tie, shoes and socks.

3. EXPOSED SKIN

It is assumed that the hands and head are not covered by clothing. These occupy respectively 5% and 6% of the total body surface area.[3] The hair is assumed to occupy under half the surface area of the head, that is, a percentage of the total surface area of the body of 3%. Its insulation is taken as 1 clo for the British male head. This value would be more in the female head and less in the American male head.

The exposed areas of skin are considered to have a mean temperature of 31° C., *i.e.*, a little lower than those of the clothed skin.

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* Paper presented at the Space Medicine Symposium, 16–17 October, 1958.

† R.A.F. Institute of Aviation Medicine, Farnborough, Hampshire.

4. Metabolic Rate

Two levels of metabolic rate are considered. All figures are calculated for a man of 1·8 m.² surface area. The levels of metabolic rate taken are then 90 kcal./hr., equivalent to sitting at rest, and 270 kcal./hr., equivalent to light to moderate work. The average heat production will probably be somewhere between the two during interplanetary travel.

5. Gravity

Two conditions are considered. The first assumes that the gravitational force is maintained by rotation during interplanetary travel, and the second that the crew are weightless. There are serious physiological objections to both these possibilities. From the point of view of heat exchange, therefore, both possibilities are considered.

The significance of weightlessness is that natural air convection round the man ceases completely, causing a large increase in its insulating power. One may gain some idea of what this means to the resting man by imagining him in a large hall completely filled with cotton wool.

The absence of natural convection is the principal point at which heat exchange between man and his surroundings differs at sea level and in the sealed cabin of a space vehicle that is not provided with artificial gravity. In the main, this problem is not severe because there must be forced ventilation in the sealed cabin. The purpose of forced ventilation is the removal of waste gases, moisture, dust and fumes, and the maintenance of a constant temperature environment. In the gravity-free state, forced ventilation removes heat which would otherwise accumulate in the place where it was produced. It is possible that the forced ventilation system may break down or have to be shut down in an emergency. For this reason the weightless condition is included in the calculations.

6. Forced Ventilation

Two conditions are considered. The first is that of normal ventilation. The figure assumed is an air speed of 100 cm./sec. past the crew members (a little over 2 miles/hr.). The second condition is where forced ventilation has failed or has been turned off.

7. Humidity

The majority of people are comfortable at humidities of between 7 and 12 mm. mercury in still air. Where there is forced ventilation with warm air, too low a humidity causes rapid drying of the exposed mucous membranes of the eyes, nose and mouth, and also drying of the skin. It is known that this may cause irritation in short-duration flights, but the long-term effects have not been investigated in detail.

A figure of 10 mm. mercury has been taken as a desirable figure for prolonged exposure (corresponding to 43% relative humidity at 25° C.).

8. Density of the Cabin Atmosphere

Ideally the sealed cabin would have an atmospheric pressure of 760 mm. mercury. The engineers would have a cabin with the lowest possible pressure in order to minimize structural weight. An atmosphere of 760 mm. mercury, composed entirely of oxygen, is not desirable because of the slight possibility of decompression sickness and the serious hazard of fire. There may also be long-term pathological consequences from breathing an atmosphere containing only oxygen and water vapour, although none is known to date. As soon as nitrogen is included in the atmosphere, its total pressure must be reduced below that at an altitude of 20,000 ft. to protect completely against decompression sickness. The pressure assumed in the subsequent calculations is one of 380 mm. mercury (18,000 ft.), *i.e.*, half sea-level pressure. It would be composed as follows:

Oxygen:	160 mm.
Nitrogen:	210 mm.
Water vapour:	10 mm.

For convective heat exchange, the insulation of air is inversely proportional to the square root of its pressure. Under conditions of still air and zero gravity, the insulation is probably inversely proportional to the pressure. The insulating power of air[4] at 760 mm. mercury pressure is 0·4 clo at a wind speed of 100 cm./sec. This is increased to 0·5 clo when the pressure is halved.

Apart from the initial calculation, where the sealed cabin is assumed to be earthbound and have a pressure of 760 mm. mercury, the pressure is taken as 380 mm. mercury.

9. Surface Available for Heat Exchange

Only a proportion of the total surface area of the body is available for convective and radiative heat exchange, because of the apposition of various surfaces. A value of 80% has been taken for convection and 75% for radiation.

10. Emissivities

All surfaces are assumed to have an emissivity of 1 in the infra-red region. One-third of the solid angle subtended at the man is assumed to be occupied by apparatus, fixtures and fittings, which are at a temperature close to that of the clothing of the crew members and which will therefore not contribute to the radiative exchange between man and his surround (some of these will be warmer and some cooler than his surface temperature). The remaining two-thirds is assumed to be walls, ceiling and floor.

III. METHOD

For the given wind speed, there are several possible combinations of wall and air temperature which would maintain a man comfortable in the sealed cabin. For the sake of simplicity only one figure has been calculated

—that where the wall and air temperature are the same. This is what tends to occur in practice when the walls are not specially heated or cooled.

Evaporative losses from the body are calculated first. For a given skin temperature, they depend primarily on air humidity and minute volume of respiration.

The combined air and wall temperature is then estimated roughly and the heat losses by convection and radiation from clothing and exposed skin are calculated for this figure. The nearest whole number for air and wall temperature which will give a combined heat loss nearest to the value chosen for the metabolic heat production (either 90 kcal./hr. or 270 kcal./hr.) is presented in Table I.

The following formulae were used:

(*a*) *Convection.*

$$H_c = \frac{0{\cdot}8\ A\ (T_s - T_a)}{0{\cdot}18\ (I_a + I_c)} \quad .. \quad .. \quad (1)$$

(*b*) *Radiation.*

$$H_r = 0{\cdot}75 \times 0{\cdot}66 \times A \times \sigma\ (T_s^4 - T_w^4) \quad .. \quad (2)$$

In these,

H_c = convective heat transfer, kcal./hr.
A = duBois surface area, m.²
T_s = skin or clothing temperature, °C.
T_a = air temperature, °C.
I_a = insulation of air, clo.
I_c = insulation of clothing, clo.
H_r = radiative heat transfer, kcal./hr.
σ = Stefan–Boltzman constant.
= 4·93 kcal./m.²/hr./°K.⁴
T_w = wall temperature, °C.

IV. RESULTS

Results are given for ten different conditions in Table I. They are discussed below.

(*a*) The first case is assumed to be in preparation for the voyage while still under sea level atmospheric conditions. The combined air and wall temperature for the resting man is 25° C., and for the working man 15° C.

(*b*) Halving the atmospheric pressure causes a reduction of these figures by 1° C. and 4° C. respectively. These would be the conditions in a space vehicle where artificial gravity was applied, or where the vehicle was in a gravitational field of 1 *g*.

It has been assumed under these conditions that the insulation of the clothing has been increased in the same ratio as the increase in insulation of the surrounding air, *i.e.*, from 1·0 to 1·2 clo in the resting man, and 0·5 to 0·6 clo in the working man. The difference in insulation between resting and working man is due to the air movement caused by disturbance of the clothing.

(*c*) Under similar conditions to (*b*), but in the absence of gravity, the insulation of clothing is assumed to have doubled for the resting man. This is due to two factors. First, convective heat exchange within the clothing ceases apart from when slight movements occur. Second, the clothes will, to a certain extent, stand out from the body, rather than hang on it. Air insulation remains at 0·5 clo because of the forced ventilation.

For the exercising man, it is assumed that the lack of natural convection within the clothing is of no consequence, because of the continual movement of clothing on limbs and trunk due to the exercise.

The temperature requirements are 18° C. and 11° C. respectively.

TABLE I.—*Analysis of Heat Exchange Under Different Conditions in a Sealed Cabin. The Clothing Assembly is Constant Throughout*

Atmospheric pressure, mm. Hg.	Air movement, cm./sec.	Gravity, *g*	Metabolic rate, kcal./hr.	Insulation, clo		Temperature of outside of clothing, °C.	Combined wall and air temperature for comfort, °C.	Heat lost by different routes, kcal./hr.		
				Clothing	Air			Convection	Radiation	Evaporation
760	100	1	90	1·0	0·4	27·5	25	55	12	23
			270	0·5	0·4	23·5	15	179	41	50
			90	1·2	0·5	26·5	24	51	16	23
			270	0·6	0·5	21·0	11	175	45	50
		0	90	2·4	0·5	21·0	18	54	16	20
			270	0·6	0·5	21·0	11	175	45	50
380	0	1	90	1·2	0·8	26·0	23	46	17	27
			270	0·6	0·5	22·0	12	168	44	58
		0	90	?2·4	?	?	?	?	?	27
			270	0·6	0·5	21·0	11	168	44	58

(*d*) Forced ventilation is assumed to have failed, but gravity is present. Here the insulation of the clothing and air becomes that for natural convection, *i.e.*, 1·2 and 0·8 clo for the resting man, and 0·6 and 0·5 clo for the exercising man. There is here a large discrepancy between the resting and the exercising man, the required environmental temperatures being 23° C. and 12° C. respectively.

(*e*) Lastly, cabin ventilation is assumed to have failed in free fall. Virtually no heat is lost by convection from a resting man, and the wall temperature must drop to 2° C. to make conditions comfortable. This value is in fact somewhat academic, as the slightest movements by the man would cause circulation of cabin air. Furthermore, there will be some diffusion of heat through still air under zero gravity, and the value of this is not known. If clothes were removed, the figure could be higher still. During exercise, however, the movement of clothing and air would definitely produce sufficient circulation of air to cool it from contact with the walls, and make the cooling effective through contact with the clothes and skin. The wall temperature in this case is 11° C. and could be higher if clothing were removed.

In this case as well as in (*d*) the crew are supposed to breathe dry oxygen from a mask and emergency supply.

V. DISCUSSION

To maintain comfort under any of the conditions discussed, the cabin air and wall temperatures required to be varied between 25° and 11° C. This assumes the crew move abour or fan themselves in an emergency. Buettner[5] states that a temperature of 0° C. is required, but he does not give details. 11° C. is convenient, because the dew point of air at a vapour pressure of 10 mm. mercury is 13° C., and if the lowest figure is fixed at 13° C. water will not condense on the walls to any great extent in the emergency, or when the crews take exercise.

It is suggested, therefore, that the walls of the sealed cabin be heated by the air which is used to ventilate the cabin, so that both will be at the same temperature under normal conditions. This temperature should be controllable between the limits 13° and 25° C., with a fixed humidity of 10 mm. mercury. Air movement is fixed at 100 cm./sec. The system should be duplicated, so that the crew are safe in the event of a failure of cabin ventilation. In the absence of duplication, the wall, floor and ceiling temperatures of the cabin should be controlled independently of air temperature, again between the limits 13° and 25° C. In the event of a failure of cabin ventilation under zero gravity, wall temperature would be reduced to 13° C., and some clothing perhaps removed.

It must be emphasized that a duplicated or separated system is obligatory for interplanetary travel. If only one ventilating unit is installed, and wall temperatures are not independently controlled, then the crew would be in danger of heat syncope if the ventilating unit failed.

VI. EMERGENCIES DURING RE-ENTRY

During the descent through an atmosphere, a space vehicle may be subjected to aerodynamic heating of such a degree that its skin temperature rises to more than 1000° C. It is vital that this heat does not penetrate to the man, for his zone of physiological protection is narrow compared with such extremes. The dangers to the man in the event of an emergency which allowed the heat to penetrate into the sealed cabin would be:

(1) *Burns.* Caused by local heating of areas of skin to temperatures above 45–50° C.

(2) *General Body Heating*, leading to impaired performance and collapse (heat syncope). This can occur in combination with burns, or in their absence. Collapse may occur when the deep body temperature has risen to 39° C.

(3) *Failure of Personal Equipment, e.g.*, sticking of the valves in a mask, due to overheating.

These problems are the problems of Aviation Medicine, as well as of Space Medicine.

They are being investigated at the moment, and preliminary results in an experimental "Hot Cockpit" indicate that man can certainly be protected against temperatures of 100° C. in the cabin by air ventilation beneath his clothing. These results may be improved in the future, particularly where aluminized clothing is used as a barrier to the transfer of radiant heat.

Time may be an important factor in the emergency. In the discussion of cabin conditioning the steady state was considered. If, however, an emergency causing excessive cabin heating during re-entry lasted only for ten minutes, it would perhaps be possible to protect the man by dressing him in arctic clothing to insulate him against the heat. For an emergency lasting more than twenty minutes, however, it is probably necessary to have a cooling system for the man himself. Considerable additional protection can be gained by pre-cooling the man before the emergency is likely to occur.[6] Air ventilation is certainly a possibility, if the air can be provided at a low enough temperature during the phase of aerodynamic heating.

It is possible that the cabin cooling unit could be reduced considerably in size if the cabin were designed to reach 1100° C. during re-entry. Under these conditions every crew member would be cooled personally during the descent.

VII. CONCLUSION

Attention to the problems of heat exchange between man and his immediate surroundings is of fundamental importance in the design of the sealed cabin of a space vehicle. I have tried to analyse these exchanges in some detail with regard to prolonged interplanetary travel, and in very general terms for the case of aerodynamic heating during re-entry. A specification for the cabin conditions in routine flight has been suggested.

ACKNOWLEDGEMENT

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HEAT EXCHANGE BETWEEN MAN AND HIS ENVIRONMENT ON THE SURFACE OF THE MOON*

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(Communication from the R.A.F. Institute of Aviation Medicine)

ABSTRACT

An analysis is made of heat exchange between man and a spacesuit, and the suit and the surroundings, at different times and places on the surface of the Moon; a distinction has been made between day and night, and for each of these cases certain assumptions have been made. Three methods of obtaining the required cooling of the suit are compared.

I. INTRODUCTION

THIS subject has been considered before by H. E. Ross[1] in his paper to the Society on the lunar spacesuit. He did not, however, present detailed calculations of heat exchange between man and the lunar environment and was more concerned with the design of the pressure suit. In this paper a detailed design for a pressure suit is not attempted, but an analysis is made of heat exchange between man and the suit, and the suit and the surroundings at different times and places on the surface of the Moon. From these calculations there emerge certain principles which must be taken into account when the lunar pressure suit is designed.

A broad subdivision has been made between day and night, and for each of these cases certain assumptions have been made. The assumptions are first considered in detail, and followed by the calculations and results.

II. ASSUMPTIONS FOR THE LUNAR DAY

1. COMFORT

It is assumed that man will walk on the Moon, perhaps for a period of hours, in a full pressure suit. It is essential that he be comfortable from the thermal point of view, and his mean skin temperature is assumed to be maintained at 33·5° C. Under these conditions there will be no active sweating, which it is desirable to avoid in a pressure suit.

2. METABOLIC RATE

The metabolic rate is assumed to be 400 kcal./hr. for the average man with a surface area of 1·8 m.^{2} Moving about in a full pressure suit requires much energy,[2] and although the suit and its occupant will be much lighter on the Moon, the effort required to move limbs will not be diminished significantly.

400 kcal./hr. corresponds to moderate or heavy work. The case of the resting man is not considered because a pressure suit which will dispose of the heat produced by a man doing heavy work will have no difficulty in removing the heat produced by a man at rest.

3. SURROUNDINGS

The man is assumed to be in the unfortunate position shown in Fig. 1. He stands facing the Sun or away from the Sun in a depression on the Moon's surface. On the side away from the Sun is a tall cliff. The solid angle subtended at the man by the terrain is taken as 240°, leaving a solid angle of 120° subtended by the sky.

4. SOLAR RADIATION

The Sun is assumed to be at 60° to the zenith, and the intensity of solar radiation is taken as 1200 kcal./m.^{2}/hr. Desert sand reflects about 25% of solar radiation[3] and the same figure has been taken for the lunar terrain.

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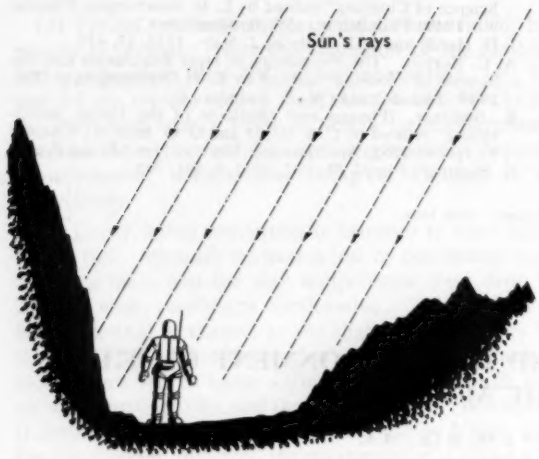

FIG. 1. Diagram showing man under the hottest conditions of the lunar day.

5. SURFACE TEMPERATURE

The surface temperature of the terrain is taken to be 120° C., which is generally quoted as the maximum, and its emissivity in the infra-red region as 1.

6. PRESSURE SUIT

The pressure suit is assumed to have a surface area of 3·0 m.^{2} This is supposed to include any packs and ancillary equipment carried by the man which are in communication with the inside of his suit. The percentage of this area available for heat exchange by radiation is assumed[4] to be 75%. When he stands facing the Sun his shadow area is assumed[3] to be 1 m.^{2} Calculations are made for three different types of surface finish to the suit, namely, black, aluminium foil in one layer, and aluminium foil in three layers. The emissivity of the black surface is assumed to be 1 for infra-red radiation, while emissivity of the aluminium surface is assumed to be 0·1 for infra-red, and 0·2 for solar radiation.

The suit is assumed to be pressurized to 160 mm. mercury and contain an atmosphere of oxygen and a little water vapour.

III. CALCULATION

Considering the man in full sunlight as described above, he will gain heat from the environment and from his own metabolic processes. It is therefore necessary for the pressure suit to have a built-in cooling system. It is clearly desirable that the cooling system be as light as possible, and it is therefore assumed that it is placed in the most efficient position, *i.e.*, next to the man's skin. A cross section of the suit will have the following layers, travelling outwards from the skin.

(*a*) Man's skin.
(*b*) Thin spacer fabric, such as a string vest.
(*c*) Space in which the coolant flows. This may be liquid or gas.
(*d*) Layer of insulation.
(*e*) Pressure-retaining layer of impermeable material.
(*f*) Outer surface of the suit.

The coolant is assumed to carry away the whole of the metabolic heat production. Considering ventilation with oxygen at high flows, this would require a temperature of about 17° C. to be maintained on the inner surface of the insulating layer.[4] It must also carry away any heat that passes through the layer of insulation from the outer surface of the pressure suit. The rate at which heat flows inwards in this way will depend on the insulation and on the nature of the surface finish of the suit. This rate of heat transfer is calculated for differing values of insulation and for the three different types of surface finish, and the results are presented graphically.

Two formulae have been used in making the calculations. The first combines the four routes by which heat is exchanged between the outside of the pressure suit and the environment. These routes are as follows:

(*a*) Direct solar radiation (gain).
(*b*) Reflected solar radiation (gain).
(*c*) Infra-red radiation from terrain (gain).
(*d*) Infra-red radiation to space (loss).

(*c*) and (*d*) are estimated from the general formula:

$$H_R = \sigma E_1 E_2 A_1 A_2 (T_1^4 - T_2^4)$$

where

H_R = heat exchange in kcal./hr.
σ = Stefan–Boltzmann constant
= $4{\cdot}93 \times 10^{-8}$ kcal./m.^{2}/hr./°K.^{4}
E_1 = emissivity of hotter object.
E_2 = emissivity of cooler object.
A_1 = radiating area of hotter object, m.^{2}
A_2 = proportion of surroundings participating in exchange.
T_1 = temperature of hotter object, °K.
T_2 = temperature of cooler object, °K.

(*a*) and (*b*) are estimated directly from knowledge of the solar constant.

The combined formula differs for the three types of surface finish:

1. Black surface.
$H_R = 3403 - (11{\cdot}1x^4 \times 10^{-8})$
2. Single layer of aluminium foil.
$H_R = 505 - (1{\cdot}11x^4 \times 10^{-8})$
3. Triple layer of aluminium foil.
$H_R = 16 - (0{\cdot}011x^4 \times 10^{-8})$

.. .. (1)

where x = mean temperature of surface layer, °K.

The heat flow through the insulation is calculated as follows:

$$H_I = \frac{R\,A\,(x-290)}{0{\cdot}18 \times I} \quad .. \quad .. \quad (2)$$

where

H_I = heat flow through insulation, kcal./hr.

R = ratio of insulation of plane surface to insulation of fabric on a man
= 0·8
I = value of insulation in clo (*i.e.*, °C.m.^{2} kcal.$^{-1}$ hr.$^{-1}$)
A = surface area of suit
= 3 m.^{2}

Different values of x are now entered in Equations (1) and (2), and since $H_R = H_I$, the value of I may be determined. The figures are presented in Table I.

IV. THE LUNAR NIGHT

Surface temperatures during the lunar night are assumed to be −150° C. Solar radiation is now absent and heat is lost from the surface of the suit to environment. However, for the case of a man working at 400 kcal./hr., this heat loss is only 40 kcal./hr. in the case of the suit whose surface is a single layer of aluminium. Cooling will therefore be needed at night as well as in the day, and since the amount is less than that required in the day, it will not be considered further, except to point out that it can be achieved quite easily if a portion of the suit's surface could be blackened.

V. COOLING METHODS

Three ways of obtaining the required cooling are also shown in Table I.

(*a*) *Black Cone.* The first embodies a device invented by Oberth.[5] This is a large cone-shaped heat radiator mounted above the man's head and communicating with the heat exchange system of the pressure suit. The cone is blackened on the inside and silvered on the outside. It is pointed towards space so that sunlight cannot enter it. The surface area of the mouth of the cone required to lose all the heat entering the pressure suit is shown in Table I. The advantage of such a device is that it does not need a supply of coolant other than that used in the circulating system, *i.e.*, it never needs replenishing.

(*b*) *Liquid Oxygen.* The disadvantage of liquid oxygen is that it requires pressure chambers to contain it and that it is very cold. It is also wasteful. A system has been suggested by Ross.[1]

(*c*) *Vaporization of Water.* Only very small amounts are required to remove heat from the suit. Vaporization is simple, but ice formation may prove a nuisance.

VI. DISCUSSION

It is clear from Table I that the suit whose outer surface is composed of three layers of aluminium foil is the most economical. Heat transfer is reduced to negligible quantities and the major effort of the cooling system is directed to the removal of metabolic heat. One layer of aluminium is good compared with a black surface, but one layer of aluminium may become damaged and lose its efficiency for reflection. The two inner layers of the three-layer aluminium suit are, however, protected from external damage.

In a suit with an external surface composed of three aluminium layers and ventilated with gaseous oxygen cooled by passage through Oberth's device, a flow of some 51,500 l./hr. (30 ft.^{3}/min.) would be required through the ventilating labyrinth of the pressure suit to remove 415 kcal./hr. The surface temperature of the black cone is assumed to be 5° C. A large flow is required for convective cooling in this way because the density is low. However, some heat is lost from the body by the evaporation of insensible perspiration and

TABLE I.—*Amount of Cooling Required in Full Pressure Suit under Different Conditions in the Lunar Day*

	Temperature of surface of pressure suit, °C.	Heat flow from environment to man, $H_R = H_I$ kcal./hr.	Insulation of pressure suit, clo.	Rate of heat removal by coolant kcal./hr. $= H_I + 400$	Cooling apparatus required		
					Black cone: area, m.^{2}	Liquid oxygen, kg./hr.	Vaporization of water, kg./hr.
Black surface	17	2623	0	3023	10·3	30·0	4·98
	50	2205	0·2	2605	8·8	25·8	4·32
	100	1258	0·8	1658	5·6	16·8	2·82
	120	753	1·8	1153	3·9	11·4	1·92
	130	458	3·1	858	2·9	8·4	1·38
	155	0	∞	400	1·4	4·2	0·72
One layer aluminium foil	17	497	0	897	3·0	9·34	1·50
	30	412	0·4	812	2·8	8·10	1·38
	40	399	0·7	799	2·7	7·98	1·32
	70	341	2·0	741	2·5	7·38	1·26
	80	324	2·5	724	2·4	7·26	1·20
	100	290	3·7	690	2·3	6·90	1·14
	150	128	13·5	528	1·8	5·28	0·90
	189	0	∞	400	1·4	4·20	0·72
Three layers aluminium foil	17	15·2	0	415	1·4	4·2	0·72
	19·5	15·1	2·1	415	1·4	4·2	0·72
	344	0	∞	400	1·4	4·2	0·72

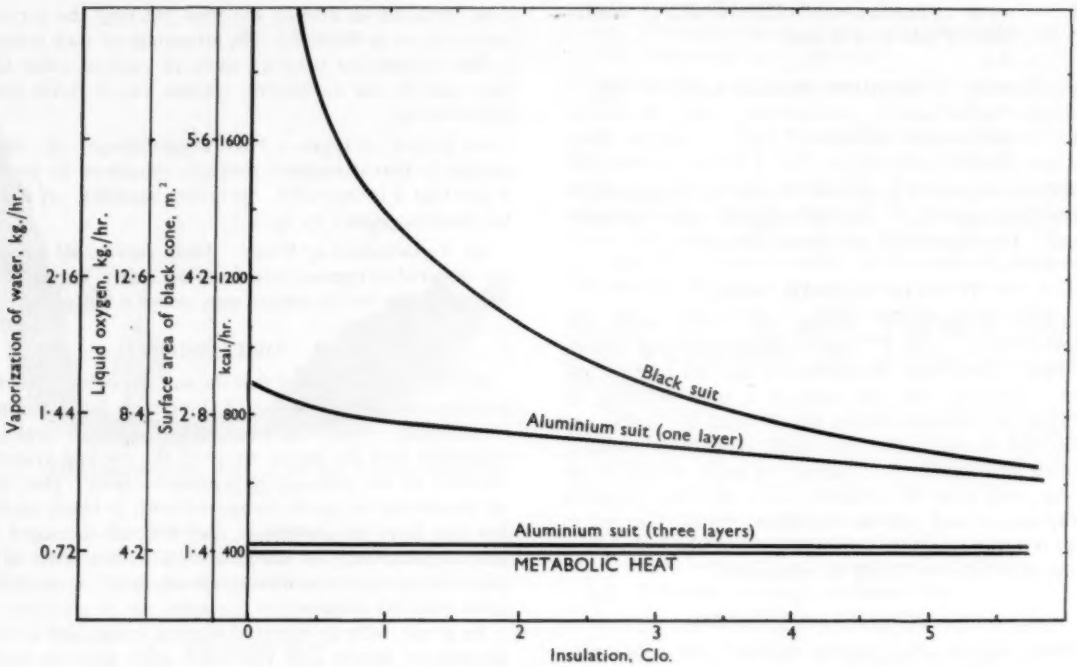

FIG. 2. Amounts of heat to be removed from three types of pressure suit, of different insulation values.

water vapour from the lungs and mucous membranes. About 100 kcal./hr. will be lost in this way, and provided it is not regained somewhere else in the system, would mean a reduction in the ventilation rate, or of the surface area of the black cone, of 25%. Ventilation with dry oxygen in the manner described above has the important advantage that the physiological defence mechanism of sweating will operate to good effect should the man become too hot.

The distribution of the ventilating oxygen under these circumstances has to be good. Otherwise local hot or cold spots will occur on the skin. For the black suit, or even the aluminium suit with one layer, temperature gradients along the length of a limb, for example, may become too great. Under these conditions it might be necessary to use a liquid coolant next to the skin to bring the temperature to a more uniform level. This is clearly undesirable, and ventilation with gaseous oxygen therefore much to be preferred.

VII. CONCLUSION

Some calculations are presented on the heat exchange problems of man in a lunar environment. The ideal surface of his full pressure suit would consist of three layers of aluminium foil with a spacer fabric between the inner layers. Under the hottest conditions in the daytime a cooling sustem would be required to remove some 415 kcal./hr., assuming the man to be working fairly hard. At night the amount is only slightly less.

It would be desirable to use gaseous oxygen as the coolant if a system could be designed to cool and distribute it efficiently. Failing this, and particularly in the case of a pressure suit which admits a greater quantity of heat than the one with the three-layered surface, the use of a liquid coolant might be necessary.

ACKNOWLEDGEMENT

Acknowledgement is made to the Director-General of Medical Services, Royal Air Force, for permission to publish this paper.

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IMPAIRMENT OF HUMAN PERFORMANCE IN CONTROL*

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(Communication from the R.A.F. Institute of Aviation Medicine)

ABSTRACT

Early vehicles for space travel are likely to have some of the features of aircraft and to carry human pilots. As it will be desirable to give the pilot as much controlling work as possible, more information is required about the amount of controlling work that a pilot can do, and about the conditions which affect the quantity and quality of a pilot's work. Two experiments in this field are described and it is shown how the results may be applied.

WHENEVER new forms of transport are devised it can be seen that two different tendencies are at work. One is to use as much existing equipment as possible in the construction and fitting out of the new vehicle, and the other on the contrary is to place great emphasis on overcoming the special problems arising out of the new travelling situation, neglecting the ordinary needs and capabilities of the person. In the case of space travel, I see these tendencies being likely to produce vehicles having much in common with aircraft, and in which great emphasis is given to the alleviation of difficulties due to the new problems such as weightlessness and radiation, leaving a number of less spectacular problems unsettled.

At least in the early period of true space-transport as opposed to the preliminary probing of space that has recently begun, the vehicles concerned will probably be controlled by human pilots. Since every attempt to install automatic control will have to face the prospect of increased payload, I presume the pilot will be given as much controlling work to do as possible. But what is possible? How much work can a man do in controlling a vehicle? What are the important conditions which affect the quantity and quality of a pilot's work?

I intend to examine briefly some general aspects of these problems and then to describe some experimental investigations as illustrations of my point of view.

I. GENERAL ASPECTS

Much of the previous research in this field has taken a molecular point of view, looking at the design of displays, controls, seats, and other parts of systems rather in isolation, and not combined into a dynamic working situation. This leaves a number of gaps in our knowledge of how man deals with whole systems as opposed to how best to design the components of the machine. It is noticeable in text-books of applied experimental psychology how small a proportion of space is allotted to current knowledge of man at work with a machine.

I have been considering a complicated vehicle where information coming from many sources is displayed to a human operator whom I am acquainted with as "the pilot." The success of the mission depends on the proper control of these variables. The first stage in analysing the pilot's task is to consider the relationship between the man, the machine and the variables. The state of each of the control systems involved may be considered to be the result of a balance between the pilot's ability and the difficulty of his task. In practice we do not see ability, we only infer it from the response to a problem; neither do we see difficulty, we infer it from the results of work. The response and the results that follow constitute performance.

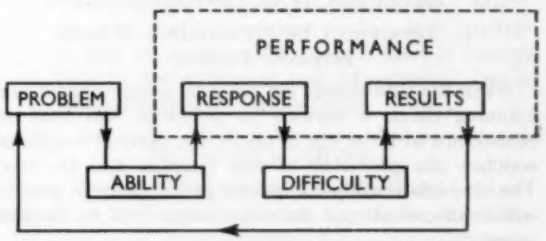

FIG. 1.

Fig. 1 illustrates not only the cyclic nature of the situation but also the relationship between the more tangible aspects, the problem, the pilot's response to it, and the results of his response; and the inferable characteristics of ability in the pilot and difficulty in his task. It would not be sufficient just to describe changes in performance as and when they occur and leave it at that. It is necessary to postulate ability and difficulty in spite of the fact that they may be awkward to define, because when changes in performance occur, it is essential to have some nomenclature for attributing them to changes in the operator or to changes in his task.

The environment, that is to say the whole set of external conditions impinging upon the person and the equipment being controlled, can obviously affect either the person or the equipment or both. The environment

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may hamper the operator in himself, or it may make his task more difficult, in which case it may well have a secondary reaction upon the operator, causing him to modify his responses. If this relationship results in a change for the worse in responses or results, we may say that performance is impaired.

It is particularly important to identify the chain of events which connect the environmental stress with its effect upon performance if we are to find the best possible way of preventing impairment. I have already distinguished between effects on the person and effects on equipment and I would also draw attention to two different classes of effects of the environment upon the person. In one the effect is inevitable, such as the weightlessness to be expected in constant velocity space travel or the encumbrance of bulky protective clothing. In the other the effect depends upon human characteristics and is much less predictable. Examples are fatigue and high temperature, both of which happen to be conditions whose symptoms can often be relieved by the application of incentives without altering the predisposing conditions.

II. EXPERIMENTAL INVESTIGATIONS

1. Impairment of Performance during Intensive Flying

When the time comes for building space vehicles and manning them, a number of problems will arise in connection with the size of crews, the optimal lengths of watches, the provision of rest facilities and the like. The time relationships of human performance in control will be discussed, and the word *fatigue* will be bandied about.

It was in a similar situation that this study took place a year or two ago.[1] The object was to obtain measurements of pilot performance and to examine them to see what changes could be detected between measurements made at different stages of a programme of intensive flying.

This experiment was concerned with long-range maritime reconnaissance aircraft, in which it is common for flights to last as long as fifteen hours. It was decided to study changes in the control of heading and altitude of the aircraft at times when the pilot was trying to fly straight and level. Since the pilot is responsible for the behaviour of the aircraft in heading and altitude, it is reasonable to argue that measurement of such records will provide information about the pilot. It is therefore permissible to discuss the results in terms of "pilot performance" as well as "error scores," provided that the complexity of the relationship between what the pilot does and what the aircraft does is acknowledged. We have to define the difficulty of the pilot's task.

A simplified view of the situation is that at a particular instant the heading, for example, of an aircraft is a composite result of:

(*a*) Recent action by the pilot,

(*b*) The effects due to the condition of the air,

(*c*) The aircraft's own tendency to vary its heading, upon

(*i*) The heading at some previous instant, and

(*ii*) The rate of change of heading at that instant.

The effects of these factors are limited to the amount of change they can produce during the period of time for which the pilot allows them to act. This period is itself partially dependent upon circumstances, such as the amount of time taken up by other work.

Each of the four crews in the experiment had four 15-hr. flights which took place on four alternate nights in a week. There were two pilots in each crew, working a watch system of about two hours on and two hours off. Thus it was possible to look for impairment in performance during a watch, during a flight, and during a series of four flights.

The measures of performance used were based on the modulus mean error, which is the mean value over a given period of the "error" without regard to sign. Here the "error" is the deviation from the required course, expressed in degrees of heading or feet of altitude.

Results

The main results, in qualitative terms, were as follows:

(1) Performance in the control of heading deteriorated considerably during a watch.

(2) Performance was considerably worse at the end of a flight than at the beginning. In fact the third of the four watches was usually the worst, and the fourth showed some recovery.

(3) Performance was no worse at the end of the series of four flights than at the beginning.

(4) Performance was not generally affected by turbulent atmospheric conditions, but there was a tendency for pilots to fly better in turbulence than in calm at the beginning of flights when they were fresh, and to fly worse in turbulent conditions at the ends of flights when they were tired.

Applications

These results point to several conclusions that may apply generally to men at work in similar situations:

(1) Continuous performance in control is not normally maintained at a steady level. Therefore, if steady performance were required, special action would be necessary to obtain it.

(2) Performance broken up into short watches may also show large changes in effectiveness.

(3) Sleep and rest between long periods of exposure to a tiring situation can prevent accumulative impairment in performance for several days, although feelings of tiredness and other kinds of behaviour may deteriorate progressively.

(4) The ability to respond to extra difficulties tends to be lost after exposure to an arduous situation. This is a loss of adaptability.

2. Multiple Tracking Test

That was one kind of study, where it was possible to measure performance at a real task, in fact to do so was the only way of getting a usable answer. I would like now to describe another experiment which demanded a more generalized approach.

In analysing the pilot's task, as I said earlier, it is most important to notice that some aspects of performance are inevitable and some depend upon the characteristics of the individual. For example, the time available has to be shared out among the systems requiring attention, and generally speaking the more time available for it, the better the job can be done. There will be a limiting number of jobs for which there is insufficient time to do them all adequately. At this point things will begin to go wrong, although the human operator may be working at the very best of his ability. Such an event is quite inevitable and can often be calculated in advance. On the other hand, one cannot build up from existing knowledge a prediction of how in given circumstances an operator will share the time available among a set of control systems. Such a problem can only be answered empirically.

Exploration of the problem of controlling a combination of systems has begun, using a piece of equipment called the *Multiple Tracking Test*. This enables a subject to work at one, two, three, four or five controlling tasks at a time, and provides measurements of about ten different aspects of performance. The apparatus consists of a console having five dials and five knobs. Certain settings of pointers on the dials have to be maintained by turning the knobs, thereby counteracting standard sets of disturbances which are fed into the equipment. In this experiment the number of dials to be controlled was systematically varied by masking the unwanted dials.[2]

Results

One of the main measures of performance used, as in the previous experiment, was the modulus mean error. This was expressed as the average number of divisions on the dials by which the pointers were out of position. In terms of this measure, the situation deteriorated considerably as the number of dials under control increased, but it would seem from other measures that the subjects who took part did much to prevent deterioration. There was a general tendency for the speed of work to increase with the number of dials. The speed of moving the hand from one control knob to another and the speed of turning the knob to make corrections both increased when there were more dials to deal with.

This increase in the speed of working seems to be a natural response to the changes in the task, a way of adapting to the demands of the situation which comes quite spontaneously. Most of the subjects were not aware of any relationship between their rate of work and the complexity of the task, and they all said that they had definitely not made a conscious decision that the best strategy would be to work faster with more dials.

Applications

The points of general interest arising from this experiment are as follows:

(1) Overall measures of performance may be misleading, because they tend to conceal the details of behaviour, so that even when things seem from the outside to be going badly, the pilot may be working at his best level of performance.

(2) Within limits, the pilot will tend to work harder the more tasks he is given to do. It is possible to take advantage of this only if there is enough time to deal with each task adequately. This is another example of adaptability.

III. CONCLUSIONS

These two experiments should suffice to show something of the kind of research that is going on at present in the exploration of impairment of human performance in control. A considerable amount of information of this kind has been collected over the years and it is up to us to see that appropriate research continues and that its findings are properly applied. A human pilot is the most economical and versatile kind of controlling equipment that can be carried in a space vehicle. The better we understand his needs and capabilities, the sooner will controlled spaceflight become a reality.

ACKNOWLEDGEMENT

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THE MAN-MACHINE SYSTEM IN SPACE VEHICLES*

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(Communication from the U.S. Office of Naval Research)

ABSTRACT

Proposals are made for an integrated approach by all concerned to the problem of finding out under what conditions a man works most happily and efficiently in a closed vehicle, whether aircraft, missile, submarine, ship or ground vehicle. The development of the U.S. Army-Navy Instrumentation Programme for providing equipment embodying optimum data presentation and control for the man-machine system is outlined, and the application of the concepts to the spaceship is indicated.

THROUGH aeons of time man has evolved as a product of the variables which constitute the Earth's surface environment. He has developed lungs to breathe the air, eyes to make use of the changing sunlight, ears to operate within the changing sound levels, and a deep muscle sense to utilize the gravitational force in order to orient his body. His sensory systems have developed as an integrated system to assist him in the one capability which elevates him above the rest of the animal form—the ability to make decisions based upon his acquisition and retention of knowledge.

In this process of evolution man has learned to create tools in the form of machines to assist him in his efforts to continue to make progress. These tools have been the fruits of his imagination and creative ability and have been developed to relieve his burden and to simplify his tasks. But man has developed these machines to meet his requirements and to assist him in making decisions. History has proven that any machine operation can take place only as a result of a man made decision. Even the most complete automatic system requires man's decisions to incorporate intelligence within it, to set it in motion, or to change its programme. It becomes evident then that man's role, even with the use of machines, is one of making decisions and therefore the environment in which he operates must be equivalent to his Earth environment, or in other words, an environment in which he can make decisions.

In order to define the requirements for a decision-making environment, we must look—not at any one aspect of the problem independently—but at the total problem, in order to understand the interaction of each component within the system.

Over the past fifty years the machine has made many radical changes—but man over some 3½ million years has changed very little.

This leads one to contemplate the idea that perhaps man can be trained over a given period of time to exist in a specific environment. It has been stated recently that "man's success has been due largely to his ability to adapt himself to new environments." In fact, there is evidence that some individuals are conducting experiments along this line, starting the subjects presumably at a very early age and subjecting them to a strange environment to which they will become accustomed. Such an approach might lower the environmental requirements, but there is one factor which must not be overlooked, at the end of the experiment you won't have men—you have something else (little man).

Since man has evolved in a very specific medium, it has been necessary, when operating within an environment different from his natural one, that he be protected from these differences and that his natural environment be maintained and controlled within his vehicle. This is even more mandatory when man moves into space. More mandatory, because in space, the distance from his natural environment is *greater*, the hazards are more *extreme*, the environment is more *challenging* both physiologically and psychologically, and the *forgiveness of errors of judgement* will be almost *zero*. If man is to operate in this manner he must be given every possible consideration. There can be no compromises such as has been permitted in aircraft and submarines, where the operators are forced at work at their maximum efficiency in order to make up for the inadequacy of equipment design (Fig. 1).

If man is to go into space we must *now* begin to place more emphasis on the consideration of man's environment and capabilities, or at least *as much as we place on the machine itself*. When we study the problems of the vehicle we spare no expenses in studies and experiments to wring the last ounce of performance from its design capabilities. We must therefore spare no expense in establishing those conditions necessary for providing an environment in which we can get maximum performance from the man.

First of all we must clearly define what we mean by an operational environment. There are two distinct ways in which man can participate in spaceflight. He can act as an important and vital link in the total loop in

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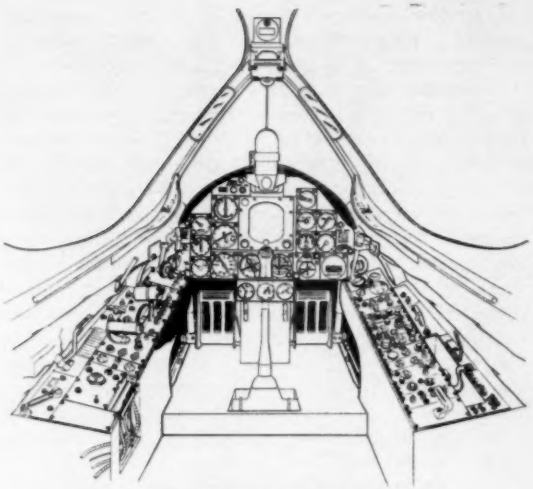

FIG. 1. Today's Cockpit.

the capacity of making decisions—or he can just go along for the ride. In the latter case, the problems are not too extreme because we can encapsulate the "subject" in a livable environment, and we can "tranquillize" him to eliminate emotional stress. We can even recover him, much as we would an instrumented vehicle, and then carefully examine his condition. But beyond the fact that we can proudly state that man was sent into space and recovered, we would not have made much of a contribution toward the solution of manned space flight.

If man, however, is to operate in space and to participate as a link in the system he must be permitted to make use of his unique facility of making decisions. In order to do this he must have an environment conducive to making decisions. In other words, he must have an operational environment which will permit him to make maximum use of *all* of his sensory systems without having to be *rehabilitated*, without *reconditioning of his reflexes*, and one which will not require extreme selective measures.

In order to establish such an environment it is necessary to examine the total spaceship. We can divide the spaceship into two specific areas for consideration. The man-machine loop or "Brain" and the machine itself or "Muscle" (Fig. 2). The machine can be further divided into structure and materials, power plant, and payload. Although the design of these elements will be an integral part of the total environment, their design must be determined by requirements established from the needs of the man-machine loop.

In analyzing the "brain" portion we must begin by stating why the ship is being designed and for what operational tasks. The *first* and *foremost* consideration is that it is to carry a man into space; *second* that the man because of his ability to make decisions will be used as a link in the system; and *third* that the operator

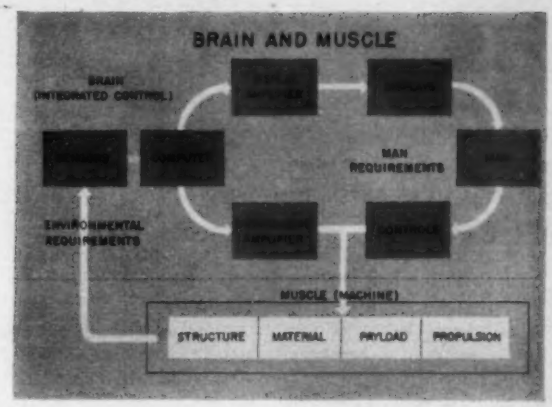

FIG. 2.

will *not be a superman* but rather an average human being.

The tasks to be performed *may* be exit and re-entry of the atmosphere, orbiting the Earth, a trip to the Moon, or a trip to other planets or even beyond the solar system. *Whatever* the task may be, the man's requirements must be satisfied and therefore are the starting point for the design.

The man's requirements fall into two main categories; information requirements and environmental requirements. This paper will not attempt to establish the detailed requirements of either of these categories because they have yet to be established through comprehensive studies. However, some of the broad requirements have been determined and can be stated.

The problem of determining what constitutes a decision-making environment can be divided into two tasks, although both must be closely correlated, and one is no less important than the other. The first is the task of determining the environmental requirements from a physiological standpoint, the second is determining the requirements from a psychological standpoint.

In order for man to make sound decisions he must operate within an environment which very closely duplicates that found in his terrestrial home. With this terrestrial environment as a yardstick we must determine the following physical parameters, and the considerations should be not how much he can take, but what is the proper environment in which his efficiency will not deteriorate:

Pressurization
Ventilation
Atmospheric composition
Humidity
Temperature
Acceleration
Vibration
Noise
Illumination
Radiation

We must determine the following metabolic requirements:

Food
Water
Waste disposal
Work/rest cycle

(These are examples, not a complete list.)

The definition of these requirements cannot be in general terms but rather in specifics because they will be used as the limiting factors by the engineers in order to design the enclosure for this environment. Pressure must be established in millimetres for normal, minimum and maximum. Temperature must spell out specific limits in degrees. Food requirements must be stated in calories per day as well as minimum vitamin and mineral requirements. There can be little or no approximations in these requirements because successful design of the entire spaceship will depend upon their accuracy.

Here the experimental investigation should *not* be made by first placing *subjects in boxes or confined spaces and observing what happens to them*; but instead by observing and tabulating man's ability to make decisions in his everyday environment, and then by analyzing the composition of this environment. Speaking of placing men in boxes, we already have one of the finest test beds available for these environmental experiments in our submarines capable of staying submerged for as long as thirty days, not to mention our high-altitude balloon gondolas. Only after we have determined what this everyday environment really is can we design controlled experiments in which factors are varied in order to determine the point at which performance in making decisions begins to drop off. This of course must be determined by simultaneously considering the psychological factors. From these experiments we can then determine not only *what* environment must be established, but within what limits it must be maintained, and in addition, how it must be controlled. The objective or goal of this initial study must be to duplicate rather than approximate the normal terrestrial environment. Such an approach does not suggest that the design of spaceships must wait until a means of duplicating terrestrial environment is found, but by seeking the ultimate, less compromise will be made for interim design, the areas of compromise will be clearly defined, and areas for further research will be better established.

The second task of determining the psychological requirements is perhaps the more difficult because the objective of these studies will be to define the factors which contribute to keeping man mentally stable in order to function efficiently in the total system.

The first step must be to determine the requirements for establishing and maintaining:

Minimum emotional stress
Maximum morale
Sufficient relaxation
Adequate habitability.

Consideration must be given to such factors as noise, colour, lighting, odours, and others which contribute to "happiness" in everyday living. To establish these requirements man must be observed in his "terrestrial home"; his habits, needs, desires, recreation, etc., tabulated and analyzed to determine those factors which contribute to or detract from emotional stability, and the degree of importance of each. We must determine for instance, whether or not music is fundamentally required, what types of diversion from primary tasks are needed, what he gains from pursuing hobbies. These must then be plotted against time in order to define the design requirements for duplication or satisfactory equivalents. Such studies must be conducted for solitary individuals as well as groups or communities. Once these parameters are determined, experiments can then be designed to again measure psychological performance deterioration by varying the factors and observing the effects.

In order to explain the concepts which could lead to the development of an optimum space man-machine relationship we have made a film which describes how we have approached the problem of aircraft, and how this concept applies to all manned vehicles.

This film presents a concept and methodology for integrating man and machine. It shows what has been done and what may be done to simplify and improve the relationship between man, the operator, and the machine he controls. It shows the concepts and methods being employed in this continuing effort.

On 9 April, 1953, at the request of the U.S. Navy, some 250 representatives of the aircraft and instrument manufacturing industries and from the Army, Navy, Marine Corps and Air Force, attended a conference in Washington, D.C. It was disclosed that the Office of Naval Research and the Bureau of Aeronautics had initiated an industry-wide programme aimed at the development of an integrated presentation of flight data. It was believed by the Navy that the necessary coordination could best be performed by an agency which would have design responsibility for the total system. Invitations had been forwarded to qualified prime contractors in the fixed and rotary wing fields.

The Douglas Aircraft Company's El Segundo Division was selected as coordinator for the fixed wing portion of the programme. Shortly after this, the Army joined the Navy in sponsoring the programme.

Later, as a result of promising work in the fixed wing field, the rotary wing phase of the programme was initiated and the Bell Helicopter Corporation was chosen as coordinator.

At the outset, it was recognized that man has basic limitations. Man-made machines will never duplicate man's brain and his ability to assume command in emergencies, yet today's high-performance vehicles confront the operator with complex mechanisms and instrumentation. His display panel presents an array of instruments which cannot be read as an entire unit. The operator must scan, choose, and interpret numerous

bits of information before he can initiate the appropriate control responses in the performance of his mission, causing undue interpretation and integration by the operator and resulting, many times, in errors, disorientation, accidents, aborted missions and deterioration of morale.

Taking the aircraft as an example, attempts have been made to align instruments to reduce the pilot's task, and attempts have been made to combine instruments, but still the problem persists. An entirely new concept of instrument presentation would have to be conceived. Without demanding maximum mental interpretation, translation and integration, the presentation should give the pilot direct responses to the questions he needs answered. Man will always remain a link in the system, whether aircraft, missile, submarine, ship or ground vehicle. Therefore, the initial step in the programme must be to create the machine around the man.

Under the man-machine approach, the operator would be concerned only with those tasks he performs most efficiently. To this end, man must have available to him certain basic information. His immediate surroundings must conform with the physiological limitations of his body. One of the building blocks of the generalized system is that of the sensors, or data-gathering elements. Constituted of these fundamental groups: electromagnetic, temperature, force, inertial, physical quantity and geometry, the sensors would send information to a central computer, which would select information necessary for operator displays and control of the vehicle. Data processing and memory storage for the entire system would be integrated into a single device, resulting in greater reliability, major savings in weight, space and power consumption. The computer would feed information into display amplifying equipment which would drive the operator's display to present data fulfilling information requirements, thus enabling the operator to take appropriate action for the situation. Simultaneously, the computer provides information to satisfy the requirement of the automatic portion of the control loop. The combined control signals are amplified and fed into the machine. It is readily seen that neglect of either man or machine requirements will compromise the overall system efficiency.

The programme's initial conception primarily concerned aircraft, but it soon became evident that the ultimate goals would be applicable to all man-made vehicles; to helicopters, to missiles, to submarines, in tanks, or in surface ships.

As the application of the long-range programme expanded, it became apparent that new methods had to be established if major progress was to be made. To establish effective direction of the diverse scientific and engineering talents involved, a suitable information flow structure was created.

The users of these systems develop operational requirements from their experience in the natural world. These requirements are divided into two groups: information requirements necessary to the operator in accomplishment of his mission, and machine or performance requirements to be used by the coordinator in directing the overall team effort. Since the man-machine system must meet these operational requirements, the information requirements for the man must be established by questioning the operators who control the system.

Conducted by the coordinator for each phase of operation, the questioning is designed to differentiate the fundamental requirements needed by all operators from those based upon unsubstantiated opinion.

The requirements are transmitted by the coordinator, along with system performance requirements, to human factors analysts who determine what functions are best performed by man in the total system, and the best displays and controls to enable man to perform those tasks. The investigations seek an optimum solution for the man and are not confined by possible limitations in electronic and mechanical equipment.

Display and control requirements determined by the human engineering team are used in conjunction with the overall system performance requirements as a basis for studies by engineering physicists, to determine what data must be sensed, the relationship which must exist between sensors, display and machine control signals, and whether these requirements can be met with techniques existing, or developmental techniques, or techniques still in the research stage. In addition, the research and development results needed before the system can be constructed, must be outlined.

The results of the feasibility studies are issued to industry for the development of specific elements in the man-machine loop, and for required research. The research results constitute advance in the state of the art to be considered by future feasibility studies.

The sub-systems and components as developed are integrated into operable systems to be evaluated by the operators working with the coordinator. Objective tests and evaluations are performed to determine whether system and information requirements have been met. The tests result in recommendations to the operating activity procuring agencies for production development and also provide new data for further human engineering studies.

In following a small portion of the total operational requirements through the implementation system, we can witness how the interaction of the various team groups brings about the integration of this portion into a flight system.

Operational activities determined that the majority of combat missions can be broken down into a number of phases, such as take-off and climb, rendezvous, cruise and navigation, strike, traffic control and landing. Although, for a number of important purposes, it has been found that all of these phases had the same requirements, it was necessary for the coordinator to question the pilots on each phase, to establish whether significant differences existed.

To uncover the fundamental requirements, it was

found that a unique method of interrogation had to be utilized. It was found necessary to continue to ask "why" after each statement by the pilot, until the interrogator's "why" questioned the validity of the objective, or until the answer could stand unchallenged. It was found, in this instance, that among the pilot's primary needs was not a compass, not a vertical gyro, but his orientation with respect to the ground plane—spatial orientation.

This method of interrogation was employed with a sizeable number of pilots to determine the basic information required for each flight phase, until a list of information requirements was unequivocally established. Since the programme's inception, no major change has been found necessary in this list, demonstrating that this method of questioning reveals fundamental information requirements.

The list of information requirements was distributed to a group of human engineers, each having been assigned specific phases of flight to study. Their task was to determine the methods by which the information would best be displayed for the pilot to operate his aircraft with maximum efficiency and minimum mental interpretation, resulting in minimum training requirements.

To determine the effectiveness of the display, it was necessary to establish a yardstick for comparison. Initially, no attempt was made to design an optimum system, but rather to design a system which would be adequate to permit the pilot to operate his aircraft under instrument conditions as effectively as under ideal contact conditions. This would then give a point of reference from which to continue the optimum display and control system determinations.

Since pilots are generally capable of operating quite effectively under ideal contact conditions, the human engineers had to determine how the visual world provided information to the information requirements. In other words, what factors in the visual world enable the pilot to operate his aircraft. It was established early in the study that there were three basic categories of information required throughout all phases of flight.

Orientation information, or "Where am I and what am I doing?" Director information, or "What should I do and when," and quantitative information, or "How am I doing?" A pilot judges his relationship to space and time under contact conditions primarily by reference to visual cues. One important visual cue was found to be an internal reference, which permits the pilot to regard himself and his aircraft as a single unit. Such a reference normally is available to the pilot in the form of a windshield. A second important visual cue is external reference. To the pilot, one of the most common external references is the horizon. It enables him to determine the relationship of his aircraft to external objects. This information alone quite often gives rise to misinterpretations. Parallel lines, apparently converging, represent linear perspective, helping the pilot to judge angular and altitude changes as witnessed in a dive. The texture of a reference surface is used by the pilot to determine slant of the surface, altitude and distance. This powerful visual cue is sufficient in itself to establish orientation without reference to the horizon. A textured surface representing the sky, composed of a distinctly different pattern from the ground pattern, provides orientation when the ground plane is not available. In air-to-air orientation, the closer of two similar aircraft would appear to be larger, indicating that size is also an important cue. Movement over the surface results in an apparent distortion of the visual field, and this is known as motion parallax. Motion parallax provides a compelling cue to distance, speed and direction of motion.

By combining the visual cues abstracted from the real world, an artificial model can be created which for purposes of orientation is preceptibly equivalent to the real world. A display created from this model may be called a contact analogue.

The real world does not, in general, contain command or director information. However, since mission objectives require operations about all three axes, such commands may be expressed in terms of desired flight path in space. Director information could be achieved in a manner compatible with cues for basic orientation. With the addition of such a flight path to the contact analogue, deviations from the command course and altitude become immediately apparent. Paths may be constructed for various manoeuvres such as traffic control, rendezvous, strike, climb out, roll and landing. It is not necessary for the contact analogue to present a surface ruled into a regular grid. It is believed that for some cases the optime pattern might take other forms such as these various representations.

In addition to the contact analogue, a display representing information on an appropriate scale is required to fulfil navigation, cruise, and tactical planning. Information concerning local geography, present position and heading, targets, destinations, flight plan, fuel range remaining and other points of tactical interest, could be integrated into such a display. The requirements for the tactical situation display and additional quantitative information have yet to be fully determined, but work is in progress in these areas.

The detailed display requirements for the contact analogue and situation display having been established were distributed by the coordinator in the form of specifications, to a number of companies with broad experience in the field of electronic systems and components development.

Their task was to determine not how to design specific equipment to produce the desired display, but rather to determine the system's technical requirements for display, data processing and sensing. Here again, as in previous studies, the same approach was taken to establish fundamentals by employing the technique of asking why until the basic requirements were evolved.

The technical requirements group determined in this example the need for development of a thin, transparent

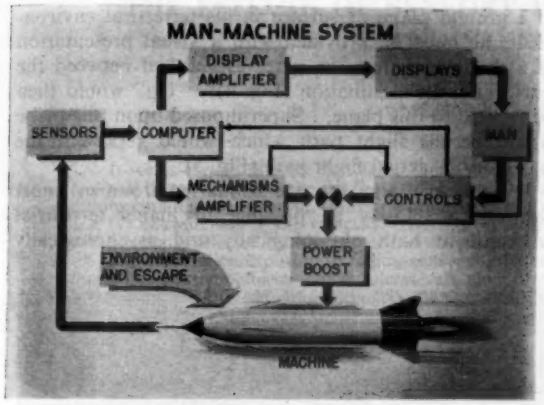

FIG. 3.

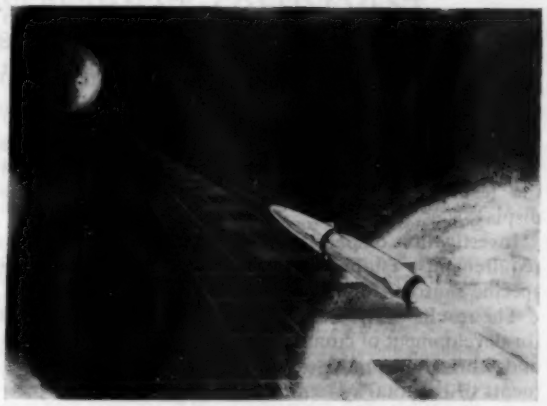

FIG. 4.

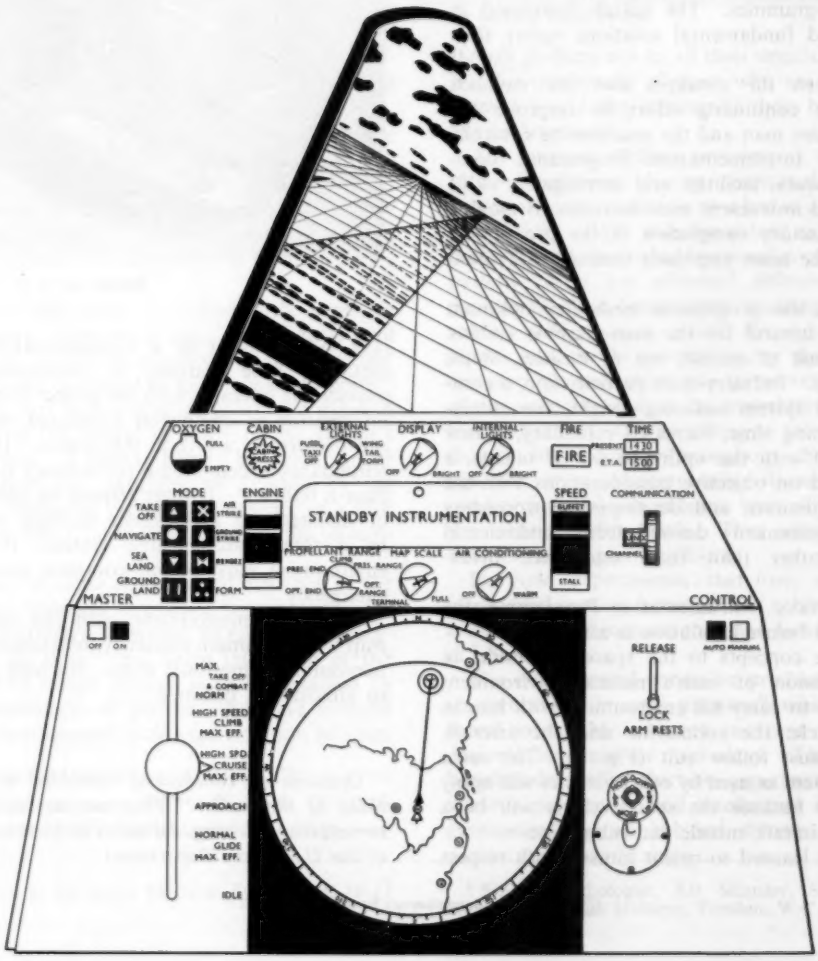

FIG. 5.

display medium. Additional examination of system and aircraft requirements indicated that one possible solution might be the development of a thin, transparent cathode-ray tube.

Studies of the equations involved in the changes within the display, established the various physical phenomena which had to be sensed, the computer requirements, and the techniques applicable for the generation of the display.

Investigation of phenomena capable of meeting these requirements, established the possibility of developing specific sensors.

The results of the feasibility studies indicated the need for development of circuit concepts, research in materials and fabrication processes necessary to meet the requirements of the total system.

Contracts for the development of sensors, computing elements and display media, were awarded as these requirements were established in the fixed and rotary wing aircraft programmes. The search continued in every case to find fundamental solutions rather than partial solutions.

These have been the concepts and the methods employed in the continuing effort to improve the relationship between man and the machine he controls. The Army-Navy Instrumentation Programme, combining the techniques, facilities and investigative skills of the aircraft and instrument manufacturers, is moving toward the satisfactory completion of the programme by adhering to the team approach method with uninhibited thinking.

In summation, the programme embodies optimum presentation and control for the man-machine system. Applicable not just to aircraft but to missiles, ships, submarines, tanks. Industry-wide participation, a completely integrated system reducing weight, size, maintenance and training time, increased reliability, a new approach method with the optimum use of talents, a programme based on objective considerations with the elimination of opinions, and development proceeding from logical requirements derived from fundamental considerations rather than from undirected invention.

In the Army-Navy Instrumentation Programme, the problem is stated before a solution is attempted.

Applying these concepts to the spaceship results in merely an extension of man's natural environment Man has learned to carry his environment with him in the surface vehicle, the submarine and the aircraft. The spaceship must follow suit (Fig. 3). The same man-machine system as used by other vehicles will apply to the spaceship because the space vehicle will be a combination of aircraft, missile and submarine.

Since man has learned to orient himself with respect to a ground plane or surface in his terrestrial environment, he must be provided with a visual presentation of a theoretical plane in space established between the Earth and the destination (Fig. 4). "Up" would then be vertical to this plane. Superimposed upon this plane would be the flight path which would represent the trajectory or actual flight path (Fig. 5).

In summary then, the operational environment must conform as closely as possible to man's terrestrial environment both physiologically and psychologically

FIG. 6.

(Fig. 6). It must be a decision-making environment requiring little training or rehabilitation. It must provide the operator with the proper display of required information so completely integrated that the operator can perform as a link in the system. It must not have redundancy except where redundancy is an asset rather than a liability. It must require an absolute minimum of maintenance and permit in-flight repair. It must be a total man-machine system; in addition, the environment must permit complete survival under any emergency.

Given this environment, man can operate his spaceship with maximum efficiency, maximum comfort, and a minimum of emotional stress—for long periods of time, to almost any distance.

Opinions or conclusions contained in this paper are those of the author. They are not to be construed as necessarily reflecting the views or possessing endorsement of the U.S. Navy Department.

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THE EFFECTS OF SENSORY IMPOVERISHMENT, CONFINEMENT AND SLEEP DEPRIVATION*

By CYRIL CUNNINGHAM,† B.A.

(Communication from the Air Ministry)

ABSTRACT

It seems certain that the first space explorers will be deprived of many of the normal sources of sensory stimulation and will be required to make the flight in a cabin of small dimensions. This paper discusses the probable effects of conditions entailing (*a*) isolation, (*b*) restriction of personal movement, (*c*) deprivation of auditory and external visual stimuli, and (*d*) unawareness of the vehicle's movement in space. It is probable that the limits of tolerance to such conditions will be greatly affected by whether or not the passenger is going to be required to take a purely passive role.

Experiments on exposure to radical sensory isolation naturally show wide variations in tolerance limits and indicate that some passive subjects could tolerate six days of the experimental condition. All subjects, however, experienced personality and intellectual disturbances, though in one in ten cases this did not prevent them from continuing the experiment. It is considered that the degree of sensory isolation in these experiments was more radical in some respects than that likely to be encountered in spaceflight and the encouraging aspects are detailed.

Evidence of the effects of prolonged exposure to sensory impoverishment, close confinement and sleep deprivation is drawn from a study of persons who have experienced foreign isolation prisons. It is argued that in terms of the situation under discussion, the prison conditions bear a close resemblance to that which is to be expected in spaceflight. The study indicates that, providing it is possible to perform activities demanding both manual and intellectual effort, some individuals can tolerate as much as seven years' isolation, impoverishment and inadequate sleep, without experiencing any gross personality or intellectual disturbances. Even if denied occupation and completely restricted in movement, some individuals can tolerate as much as three weeks without breaking down. The longest period of total sleep deprivation recorded in the study was thirty-one consecutive days. Of two such cases, one experienced no gross disturbances of personality or intellect. Both were subjected to a high level of sensory stimulation in order to keep them awake.

I. INTRODUCTION

THE conditions under which the first space explorers will be required to operate must be to some extent conjectural until a good deal more is known about the design and performance of the man-carrying vehicle. It seems certain, however, that the passenger will be deprived of many of the normal sources of sensory stimulation, and, because of considerations of weight, will be accommodated in a compartment the dimensions of which are likely to be small.

The purpose of this paper is to discuss the probable effects of sensory impoverishment, confinement and sleep deprivation. It will be assumed that the passenger will be (*a*) alone, (*b*) restricted as to personal movement, (*c*) for the most part deprived of auditory and external visual stimuli and (*d*) largely unaware of the vehicle's movement in space. A human being's behaviour under such circumstances will naturally be affected by the duration of the flight, the presence or absence of a task and the extent to which he is able to control the passage of the vehicle.

Although there is some experimental evidence of the effects of sensory isolation, it has not been possible, for practical and humanitarian reasons, to make laboratory studies beyond six days. But some indication of the probable effects of longer periods is to be obtained by studying the experiences of persons who have suffered many months' confinement in foreign isolation prisons.

II. EXPERIMENTAL EVIDENCE

The pioneering experiments of Professor D. O. Hebb and his associates at McGill University[1–3] are well known, though perhaps not in all their details, to psychologists. But for the benefit of those who are not familiar with them, I would like to describe them briefly and make a few comments.

The purpose of these experiments was to study cognitive functioning during perceptual isolation. Each subject was required to lie on a bed in a cubicle measuring 8 ft. × 6 ft. × 3½ ft. wide for as long as he could. Visual perception was restricted by special goggles that prevented pattern vision but admitted diffused light; auditory perception by a background masking noise and foam rubber pillows upon which the subjects rested their heads, and tactile perception by the use of specially designed gloves. Attempts to prevent the movements of the subjects had to be abandoned because it was found that they were unwilling to tolerate this for more than a few hours. Throughout the experiment the cubicles were continuously illuminated and air-conditioned and the subjects were allowed out to visit the toilet and for meals. They were also allowed to sleep for as long as they liked.

In these experiments, therefore, only partial and interrupted sensory isolation was achieved, but none the less it was more extreme than had hitherto been achieved in laboratories.

The experimental condition produced in the subjects an increasing "mental pressure" which most of them found intolerable. Ninety per cent. had to be withdrawn after three or four days. The remaining 10% lasted six days, after which the experiment was terminated. Various personality and intellectual disturbances were experienced by all subjects during isolation and in

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several cases these persisted for varying periods after withdrawal from the cubicles. For most of the isolation period the subjects displayed a curiously flat emotional state, interspersed with periods of mounting tension, irritability, restlessness and inability to sleep.

The intellectual disturbances observed included a steady deterioration of performance on intelligence tests, inability to concentrate, increasingly frequent periods of daydreaming and hallucinatory activity. Some subjects reported feelings of depersonalization with somaesthetic hallucinations.

III. COMMENTS

These results, while indicating that a certain kind of sensory isolation can be psychologically hazardous, are not without a number of encouraging features.

In the first place, one assumes that the space explorer will be able to perceive within the limits of his cabin and will not be deprived of pattern vision or prevented from touching objects within his reach. He will also have to attend to certain bodily needs including, perhaps, adjustment of oxygen flow and so forth. In this respect, therefore, the degree of isolation may not be as radical as that in the experiments and his immediate environment is more likely to resemble the cockpit of an aircraft. Also, in the experiments, most subjects were motivated by cash rewards and could withdraw from the cubicle when they felt unable to continue. For the space explorer, self preservation is likely to be a powerful incentive to maintaining his mental equilibrium, especially if he has no means of terminating the flight of his own accord.

Secondly, it is encouraging to note that subjects motivated by monetary incentives and able to withdraw when they liked, could tolerate passive exposure to radical isolation for a minimum of three days. The maximum was set by the termination of the experiments. Consequently, although approximately one in ten reached the six-day limit, this does not represent the upper limit of their endurance. One or two of the subjects expressed themselves willing to continue.

Thirdly, the "intolerable mental pressure" of which the subjects complained and which, presumably, constituted one of the main reasons for giving up was, according to one report, primarily the result of boredom. The same kind of condition is unlikely to arise if the subjects are kept fully occupied.

The fourth point to note is that the subjects did not immediately withdraw from the cubicles at the onset of personality and intellectual disturbances. The extent to which such disturbances contributed to the loss of motivation is uncertain. It would be interesting to discover whether or not the loss of motivation was closely related to the degree and type of hallucinatory activity. In any case, the results indicate that despite perceptual disturbances and vivid hallucinations, some subjects were able to tolerate at least six days of radical isolation.

The fifth encouraging feature is the fact that half of those who tolerated six days were experimenters acting as experimental subjects. This suggests that familiarization with the experimental conditions and, possibly, the effects to be expected, and also stronger motivation, may do much to extend toleration limits.

IV. EVIDENCE OF FORMER PRISONERS

The evidence of the effects of more prolonged exposure is drawn from a sample of people who experienced a characteristic pattern of imprisonment.[4] This included solitary confinement in barren isolation cells for periods ranging between seven days and seven years, during which time they were denied occupation and news of the outside world. For much of this time strict silence was enforced. Most of them were kept on a short ration of sleep, usually about five hours a day. They were also usually exposed to extremes of temperature and their diet was low, debilitating and tasteless.

This situation would seem to be akin, in terms of the degree of confinement and sensory impoverishment, to that which can be envisaged in spaceflight. It also has the advantages of the inability of the prisoner to terminate the condition and motivation based upon self-preservation.

It is clear from the study of such cases that psychologically, the most hazardous combination of circumstances is close confinement, extreme sensory impoverishment and denial of occupation demanding both manual and intellectual effort. This produced extensive breakdowns of personality and intellect and often resulted in psychotic episodes and well developed paranoid syndromes within about three weeks.

The critical aspect of such cases was that, when forced to sit in idle contemplation, the prisoners almost invariably endeavoured to maintain their equilibrium by resorting to constructive intellectual activities, such as mental arithmetic. Equally invariably they soon found that they were unable to concentrate and remember, and their minds began to drift first into directed daydreams and then into aimless daydreaming. This was usually followed by hallucinations over which they seemed to have no control.

In almost all cases hallucinatory activity seems to have precipitated breakdown; the prisoners believed it to be a sign that they were losing their sanity. It was often the fear of becoming insane, reinforced by continuing and grotesque hallucinations, that finally made them give in to their captors.

Such evidence seems to be important for three reasons. Firstly it suggests that some individuals are capable of enduring a high degree of sensory impoverishment for several weeks before their mental condition becomes seriously affected. Secondly it shows that intellectual activity alone can only delay an intolerable psychological condition for a limited period. Thirdly it suggests that hallucinatory activity is one of the primary factors in breakdown, mainly due to ignorance of its true implications.

Some of the prisoners, though held in the conditions described, were nevertheless able to amuse themselves with all kinds of activities, though these were prohibited according to prison regulations. Significantly, these prisoners did not experience any gross personality or intellectual disturbances. An outstanding example of this kind is the case of Dr. Edith Bone, who endured seven years in an underground isolation cell. There are many such cases in the sample and in none of them was there evidence of chronic hallucinatory activity. They focus attention upon the kind of occupations adopted by the victims. In most cases these were relatively trivial but were of enormous importance to the victims at the time. They included such activities as finding the means of communicating in writing with other prisoners, scheming and obtaining relative luxuries, making sundials, drawing and doing sums in the dirt, taming rats and insects, manufacturing useful articles from rubbish, etc. In other words, these activities were not only purposeful but demanded both manual *and* intellectual effort.

This illustrates the importance of varied and purposeful activity to the stability of human behaviour. What is purposeful is relative to the prevailing conditions and very often will be more trivial as circumstances deteriorate and are prolonged. There seems to be a very strong tendency in prisoners to obsess themselves with trivialities and there is some evidence to indicate that an impoverished environment leads to an impoverishment of thought, a depletion in the variety of conceptual activity. Thus in spaceflight, the welfare of the passenger may depend upon keeping him fully occupied with as great a variety of activities as is possible and these must seem to him to serve useful purposes.

V. SLEEP DEPRIVATION

It is well known that prolonged and total sleep deprivation can produce personality and intellectual disturbances. The classical experiments[5–15] may be criticized, however, on the grounds that the subjects were not kept purposefully occupied between test periods. Little is known about the effects when the subject is continuously stimulated by purposeful activity.

In general, the effect of continuous wakefulness for periods ranging between thirty hours and three days is a condition which, in many respects, resembles alcoholic intoxication. But there are naturally considerable individual differences. Some people begin to experience hallucinations after thirty hours' total sleep loss while others suffer no gross disturbances after two weeks. There are cases where people, who have suffered injury to the sleep centres of the brain or are afflicted with continuous hiccoughs, have not slept for several months or years. Apart from such unusual cases, the longest period of continuous total sleep loss to come to my notice during my studies of prisoners was thirty-one consecutive days. Of two such cases, one displayed no apparent gross disturbances of personality or intellect at the end of this time.

I think that it is often the fear of the consequences of total sleep loss that precipitates abnormal conditions; there appears to be a popular belief that prolonged lack of sleep causes insanity, probably because of the hallucinatory and other perceptual effects it sometimes produces. Much, therefore, seems to depend upon one's attitude. Some marathon feats of sleeplessness are daily being performed by parents of young children and those nursing ailing relatives, without any profound effects. If those same people were asked to repeat their performances in the laboratory they would in all probability fail to do so.

Naturally the normal healthy individual is unlikely to remain awake indefinitely of his own accord and needs to be stimulated at a fairly high level to keep him awake for more than twenty-four hours. But sleep is a habit and it is my own personal experience and that of others engaged upon certain military exercises, that after about fifty-five hours' continuous wakefulness it is extremely difficult to go to sleep even when conditions are conducive to doing so.

VI. CONCLUSIONS

An attempt has been made to describe the probable effects of confinement, sensory isolation and impoverishment and sleep deprivation. The experimental evidence and the evidence of former prisoners indicate that there is a level of sensory deprivation below which the consequences may be psychologically serious. This level naturally varies between individuals and would seem to depend upon a number of factors, principally whether or not the space explorer is going to be required to adopt a passive role. If one is to avoid reducing him to a pathological condition, three weeks would seem to be the limit for a passenger in a passive role. Whatever his role is to be, the limits of tolerance may be raised by careful selection of personnel according to their established ability to withstand the conditions. It may also be raised further by familiarizing the selected individuals with both the environment in which they are to operae and their own psychological reactions to it. If the journey involves more than twenty-four hours, then the space traveller may have to be stimulated at a high level especially for the first two or three days and it may be possible to train him to stay awake for, perhaps, a few weeks.

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SOME PROBLEMS OF SPACEFLIGHT FEEDING*

By S. W. F. HANSON,† M.Sc., F.R.I.C., Dip. Ed., M.I.Biol.

ABSTRACT

The phases of man's exploration of space may reasonably develop in four stages. Firstly, a short orbital flight lasting hours; secondly, a lunar excursion lasting days; thirdly, a planetary trip lasting months; and finally, long-term extraterrestrial existence.

Each of these phases poses a different feeding problem, and recent advances in food technology suggest answers to some of them. The first phase is essentially an extension of the latest manned aircraft situation, for which foods and systems have been developed for feeding pilots through oxygen masks. The second seems an ideal case for the use of dehydrated foods, which are not only light in weight but which are stable without refrigeration. Moreover, the continuous accretion of water from metabolism adds to the argument for dehydrated foods, which can now be made in attractive and nutritious form, rapidly reconstitutable and even pre-cooked, so that the mere addition of hot water produces an "instant meal." The interplanetary journey lasting for months to years requires, it would seem, the establishment of a micro-cosmic plant-animal balance which is yet far from feasible, and the continuous subsistence on other heavenly bodies might involve intriguing "unnatural" biological problems.

BEFORE preparing the picnic basket for a space voyage, one wishes to know how long the travellers will be out—and what will be the environment of the space traveller. Let us first deal with the latter point.

In searching for information on living conditions in the spaceship itself one is faced with a multitude of views. It would appear that the traveller is likely to be faced with many hazards, among which we can count tremendous accelerations, collision with meteorites large and small, solar heat and other radiations, cosmic radiation, suffocation, starvation and thirst; not to mention psychological stresses.

It has been encouraging to sense the feeling at this Symposium, put forward explicitly by Commander Hoover's team, that in the man-machine complex of the space vehicle so much depends on the ability of the man to make correct decisions that he must be a "normal" man capable of "rational" actions. Which means, in effect, that the machine must be built around the man rather than that the man be installed in a hole in the machine. The aim, therefore, should be for duplication of his terrestrial environment as far as possible, requiring as little adaptation or training as possible, and a minimum of emotional or physiological stress. Where it is not possible to conform closely to this ideal, the shortcomings must be clearly defined and their specific effects made the subject of further research.

With this in mind I can only consider the feeding of our traveller if his continued existence is otherwise assured, by the provision of oxygen and the removal of carbon dioxide and water vapour from the air, by adequate air pressure, by temperature control, by protection from radiation, and by such arrangements as seem possible to deal with all but catastrophic puncture.

On the subject of acceleration, it has turned out that this need not be the terrifying factor of earlier writings; but the intriguing problem of artificial gravitation is not easy to resolve. There are those who claim that weightlessness would be no problem, but since the only available evidence comes from a few experiences for periods of seconds, in special manoeuvres by high-speed aircraft, during which some of the subjects felt comfortable and some felt sick, it would be improper to jump to conclusions.

It seems true that the bodily functions of eating, drinking and excretion are controlled by muscles and are largely independent of gravitation; but this is of little assistance to gracious living if, for example, your drink will not remain in its glass—to mention but one possible embarrassment. On the whole I feel sympathetic to those designers who have imagined the living-quarters, at least, of their vehicles to revolve to produce an artificial gravity. This would, of course, increase towards the walls, upon which the crews would walk, and it would produce the odd effect that if they were in a standing or sitting position their food would increase in weight as it went down. One can picture them therefore, reclining on couches on the wall, to eat in sybaritic posture in an air-conditioned atmosphere.

But let me break down the phases of progress into space into four stages, and deal with them separately. Firstly, we might expect a short orbital flight lasting for

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hours, or at most a day or two. This is essentially an extension of the latest manned aircraft situation and calls for an oxygen mask, pressure suit and relative immobility of the pilot. When one gets down to the details, the feeding problem here is already capable of solution. For a short time it is debatable whether food is needed at all. There is plenty of evidence that water is. Feeding systems have been developed and are currently being tested, wherein liquids such as fruit juices or flavoured milk can be supplied from containers with special attachments leading by flexible tube through a port in the oxygen mask. Semi-fluids such as thick soups and homogenized meats and vegetables can be squeezed out of flexible tubes (similar to tooth-paste tubes) with long nozzles going through the mask. Solids such as finely comminuted sticks of meat and other products can be fed in similar fashion from containers like screw-up lipstick cases.

When it comes to getting away from the Earth, we need to have some picture of the duration of the expedition. Since both the starting points and the objectives of space journeys will always be moving at great speeds on different orbits, and the space machine will be moving at great speed on a third orbit, complex calculations will have to be made. For our purposes, two kinds of journey may be considered. Firstly, a voyage to the Moon will take about five days each way, but the expenditure of so much resource and physical energy could hardly be justified without a lunar exploration lasting some days. Let us then consider that a visit to the Moon lasts a couple of weeks. The ultimate goal of spaceflight will, however, undoubtedly be an expedition to one of the nearer planets. And these are not so near. At their closest Venus is about 26 million, and Mars about 35 million, miles away; so that the shortest interplanetary journeys would take over three months for the outward journey and at least 15 months for the round trip. The excursion to Mars is commonly reckoned as a three-year affair.

These considerations pose two different feeding problems, and we shall consider the conditions of the lunar excursion first. It has been argued at some length that for periods of a week or two the most economical method of atmosphere regeneration in a spaceship would be to absorb carbon dioxide chemically (and we shall not enter into the controversy as between the lighter lithium oxide or the more efficient calcium oxide, or between regenerative and non-regenerative systems), and to provide oxygen from a supply of liquid oxygen. Water vapour seems best removed from the air by refrigeration equipment, as in everyday air-conditioning, and this gives an opportunity to control the air temperature at the same time.

In this closed system there is a continuous accumulation of water derived from the traveller's metabolism, and exhaled, perspired and excreted by him; and therefore the situation seems quite ideal for the use of dehydrated foods. Start with a little water to rehydrate and accompany the first meals, and not only can that water be recovered, but also the additional water produced by oxidation of the food itself.

The quite apparent advantage of dehydrated foods are threefold. Since some four-fifths of meat and fish, and nine-tenths of fruit and vegetables consist of water, which is removed by the process, they are intrinsically light in weight. Since they do not require high processing temperatures and pressures as used in canning, they can be packaged in non-rigid lightweight containers. Since they are non-perishable they can be stored without refrigeration equipment.

They need only ease of preparation, palatability and nutritional quality to justify their claim to a solution of this problem. Recent advances in food technology have brought these requirements to realization. Freeze-dried foods (brought within commercial feasibility by British developments in accelerated freeze drying) are of prime nutrient quality, attractive in appearance and flavour, and can be made up into a wide variety of meals. Moreover they are reconstituted almost immediately on the addition of water, and can even be pre-cooked so that the mere addition of water, or a short period of heating, is sufficient to prepare a meal. A generous and attractive menu can be provided by 2¼ lb. of such food per man per day.

Now we turn to the more formidable proposition of interplanetary journeys lasting for several years. There is a curious unanimity on this subject by the many authors who have referred to it and who have been intrigued by the possibilities of a microcosmic biological cycle. Given solar energy—and it would seem hard to avoid that—the conditions appear to call for an attempt at setting up a balance so that the photosynthesis of plants would consume carbon dioxide and water, at the same time producing oxygen and plant tissues which could be consumed by humans. Nitrogen, sulphur, and mineral cycles would also have to be organized, but academically the suggestion is attractive.

It is when they are closely studied that the proposals make one grateful that they refer to a possibility which is still a good way off.

For one thing, the engineering problems indicate that the light necessary for photosynthesis must be generated within the space vehicle, and we immediately hit up against the inefficiency of light sources. This has led to some concentration on this phase of the problem and a U.S. Air Force report indicates that the provision of adequate gas exchange equilibrium with one man would require about 8 ft.^{3} of algal suspension and about 80 ft.^{3} of equipment for lights, pumping and gaseous exchange. In the discussion on Commander Hoover's paper, Dr. Sheets indicated that with a more efficient lamp his equipment only occupied 3 ft.^{3} Both sources mentioned admit the enormous power requirements of such a system, the former stating that 10 h.p. of heat per man must be dissipated. This implies more weight for the power equipment and more weight for the consequent refrigeration equipment.

Without going into further argumentative engineering details about *Chlorella* culture, let me say that to my mind quite unjustifiable calculations have been made to fit the process into the spaceship requirements from the results of an extremely limited number of pilot plant experiments carried out under quite different conditions. On the biological side, one point which springs to mind is the suggestion that water could be recovered from urine by an ion exchange apparatus. If, by any chance, this had not 100% efficiency throughout its perpetual cycling, then the water produced would become more and more saline and it would therefore seem profitable to investigate the characteristics of organisms more tolerant to brackish water than is *Chlorella*. Similarly the treatment of faeces has frequently been dismissed by the suggestion that they be incinerated and the ash used as fertilizer for the plants, without any evidence being presented that it is indeed assimilated by *Chlorella*. It is most unlikely, and at the moment it seems that a miniature sewage treatment plant is needed, of compact biological and engineering design, but undoubtedly adding still more weight.

Finally I would suggest that to keep the system going indefinitely without contamination or infection by plant or animal pathogens, and without reduction in output, presupposes a biological control rarely found elsewhere. Indeed the culture of algae has raised more problems than it has solved.

I have not even mentioned the psychological revulsion such a system must produce, for it would seem little better than drinking one's own bathwater. Indeed, in such a microcosm it would appear more than likely that one might be brought, of necessity, into nauseating intimacy with the process, universal in the macrocosm of Earth, of second- or third-hand cannibalism.

Nevertheless none of these considerations are the basis of my present rejection of *Chlorella* culture as the solution to the interplanetary feeding problem. Even if research and development produced a compact and operational piece of equipment to grow the organism the fact would remain that *Chlorella* is not *food*, despite its content of nutrients. Humans cannot be expected to live on an interminable diet of green paste, and, indeed, there is no evidence that they are able to do so. This has been the obstacle to many bright ideas for coping with the world's problems of nutrition (as witness the frustrating experiences on *Torula utilis*, fish flour and leaf proteins), and until it is solved no progress will be made along these lines.

Moreover, the suggestion that algae be the mainstay of the diet of interplanetary travellers goes no part of the way towards meeting the human requirements of the man-machine complex, for it has often been found that in stress men demand foods of comforting familiarity. The fictional notions of an array of coloured pills sufficing for the maintenance of life in such circumstances is ridiculous even if it were nutritionally possible; which it is not.

In saying that the space-feeding problem for lunar voyages is already soluble, and that for interplanetary voyages is not, I have commented on the travelling phase of the subject; but before I conclude I would like to air a few ideas about the next phase beyond—that of producing food on the Moon or planets. It seems that on the Moon one would have to provide an artificial atmosphere and a closed gas and water-vapour system, which might be possible by an application of our knowledge of hydroponics. There is a suggestion that below the Moon's surface there are enormous caverns with relatively small openings. These would offer some protection from radiation and meteorite bombardment as well as insulation from the violent extremes of heat and cold.

Of the planets little is known, but it seems feasible, from a consideration of the limitations of temperature, pressure, light energy, and chemical composition of the atmosphere, that on Mars there could be lichens, with their peculiar "internal atmosphere" and algal symbiosis; and on Venus there could be elementary forms of life in certain layers of the surrounding clouds—a "bio-aerosol."

Whatever may be found in space, let me suggest some possible hazards. For one thing you will recall the defeat of the Martian invaders in Wells' "War of the Worlds," by terrestrial infections against which they had no immunity. If organization on the planets has at least reached that vague transition stage between large molecules and living matter inhabited by viruses, for example, there may be infections catastrophic to man or his plant food. Moreover, anaerobic forms of life might exist which would "detoxicate" all forms of life producing oxygen, which would be as lethal to them as chlorine is to us.

Finally, I should not like to leave this depressing tale without recounting Haldane's observation that molecules of living substance have the same kind of asymmetry, and yet their mirror images would probably work just as well in a system which by chance could have developed along analogous evolutionary lines. Such compounds could conceivably constitute living material on Mars or Venus, in which case we would find food on these planets without nutritive content (except for the symmetrical fats) and indeed, by "steric hindrance" they might block the normal processes of metabolism at a vital stage, and be fatal.

One reaches the conclusion that even when technique and foresight permit space travellers both to leave Earth and to return it would be well to arm them with the fullest possible range of antibiotics (and their optical isomers) and quarantine them, lest they return only to devastate the food supplies of mankind.

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HUMAN FACTORS IN A SPACE CABIN, WITH SPECIAL REFERENCE TO WEIGHT AND ECONOMY*

By L. G. C. E. PUGH,† B.M., B.Ch., M.A.

(Communication from the Medical Research Council)

ABSTRACT

Human problems in space travel are considered in the light of experience of extreme conditions of hypoxia and climatic stress on Mount Everest. Methods of saving mass (1) by reduction of the air pressure in a space capsule, (2) by choice of lightweight personnel, and (3) by economy of food and fluid, are discussed.

On the way back from Mt. Everest in 1953, I received a cutting from a New York newspaper containing a comment made by my seven-year-old son on being told that Mt. Everest had been climbed. His reply had been "Now they will have to get on with the rocket to the Moon!" Only five years later I find myself asked to speak on this very topic.

Ascents to heights above the Earth's atmosphere in a sealed cabin or capsule present very different problems from those of terrestrial altitudes. Yet there are perhaps one or two respects in which experiences gained on the Earth's highest mountain may be of use in this new sphere of human endeavour.

One of these is the effect of extreme environmental conditions on the mind. On all expeditions to Mt. Everest it was found that European members of the assault parties did better than the Sherpas at heights above 25,000 ft., although the Sherpas acclimatized better and had more endurance at lower altitudes. This finding has been attributed, probably rightly, to the fact that the British climbers had an intense desire to reach the summit, whereas the Sherpas were only doing a job to earn money. Because of their greater resolution the British climbers were able to push themselves to greater limits of physical endurance.

Another feature revealed on Mt. Everest was that the climbers retained their skill and judgement in technical mountaineering matters long after they had begun to show signs of mental impairment in other respects. They were also able to carry out pre-arranged plans in detail, but were unable to adapt themselves to unforeseen circumstances, not connected with the actual climbing.

The lesson suggested by this experience is that the space traveller should be dedicated to his task, extremely well trained in all his technical procedure so that he does not fail under stress, and prepared by long practice to deal with all conceivable emergencies.

Another aspect of expeditions to Mt. Everest which has something in common with the problem of space travel is economy of weight. Prior to 1953, Everest parties had never been willing to accept the weight of fuel and stores necessary for their maintenance in a proper state of health at great altitudes. All the time above 20,000 ft. they subsisted on 1000–1500 kcal. of food a day, whereas their calculated requirement was about 3500 kcal. This low food intake was due not so much to lack of supplies as to inability to prepare proper meals for lack of pressure cookers and adequate supplies of fuel. For the same reason, being unable to obtain sufficient water from snow, the climbers became severely dehydrated and some members of assault parties passed no urine for 18–24 hr. There is little doubt, in fact, that starvation and dehydration were prominent causes of high-altitude deterioration in addition to the more obvious one of chronic anoxia, and that high-altitude deterioration was one of the principal reasons for the failure of expeditions to Mt. Everest prior to 1953.

The designers of space cabins will be in much the same position with regard to weight economy as the mountaineers. Although the time is passing when engineers design machines with little thought of the men who are to operate them, there will undoubtedly be a temptation on their part to cut down on the basic physiological requirements of the occupants in order to save mass, because the ratio of propellent to useful load in a space rocket is, I understand, of the order of 400 to 1. It is worth while, therefore, to enquire into the means whereby mass might be legitimately saved.

I. CABIN PRESSURE

The structural mass of a space capsule can be considerably reduced by lowering the barometric pressure inside the cabin. This may be achieved (*a*) by replacing nitrogen in the cabin atmosphere with oxygen and (*b*) by reducing the oxygen pressure below the normal sea-level atmospheric oxygen pressure.

At sea level the partial pressures of the lung gases (excluding nitrogen) are:

Gas or Vapour	Partial Pressure, mm. Hg.
H_2O	47
CO_2	40
O_2	110
Total	197

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If nitrogen in the air inhaled is replaced with oxygen, the total pressure required for sea level oxygen partial pressure in the lungs is 197 mm. mercury, which is equivalent to the atmospheric air pressure at a height of 33,000 ft.

Since the effects of oxygen lack in healthy adults are insignificant below 8,000 ft., it would be legitimate to reduce the total cabin pressure to a level at which the oxygen pressure in the lungs of the occupants is equal to the lung oxygen pressure when breathing air at this altitude.

If, however, the crew were previously acclimatized at a height of 18,000 ft., their breathing would be adjusted to maintain the following gas pressures in the lungs:

Gas or Vapour	Partial Pressure, mm. Hg.
H_2O	47
CO_2	25
O_2	45
Total	117

and the total pressure in the capsule might be reduced to 117 mm. mercury—a level equivalent to atmospheric air pressure at 45,000 ft.

As is well known, pure oxygen at sea level pressure has a toxic effect on man and animals if breathed for more than 24 hours and the fire hazard is very great. These disadvantages are, I understand, no longer present at the reduced oxygen pressures under consideration.

Experience on Mt. Everest and other high mountains has shown that with suitable acclimatization one can live for many weeks at 18,000 ft. in a satisfactory state of health and vigour and without significant mental impairment apart from a slight degree of lassitude and retardation. But would the astronaut tolerate the added stress of altitude in addition to all the other stresses to which he would be exposed? Would it not be wiser to accept the mass penalty to give him a sea-level atmosphere? Experience already gained with high-altitude balloons in which only moderately reduced atmospheric pressures have been used (*viz.*, pressure altitude of 10,000–13,000 ft.) suggests that without prior acclimatization it would indeed be wiser to have an oxygen pressure near sea-level value.

II. BODY WEIGHT AND METABOLISM

Another means of saving mass would be to select men of light weight to act as crew. Small persons not only weigh less but they eat less food, absorb less oxygen and exhale less carbon dioxide than large persons. As a matter of interest, I have enquired about midget circus performers, a colony of whom exists in Germany. These little people weigh less than 50 lb.; however, their intelligence is not high enough for the purpose under consideration. Generally speaking, women are smaller than men and seem to tolerate food restriction more easily. Many women live for long periods on diets of 1000 kcal./day or less for the sake of their figures without obvious impairment of mental or physical vigour; women might also prove suitable from a psychological point of view.

By the selection of very small personnel it would be possible to man the space capsule with two persons instead of one, which judging from experience in other fields, would be a very great psychological advantage.

In addition to a light-weight crew, further saving of mass could be achieved by some restriction of food and fluid. We do not know what effect the conditions of space travel (*e.g.*, the absence of gravity) would have on metabolism, but for the sake of argument let us compare the mass of food and fluid consumed by a 75-kg. man on a 2500-kcal. diet of ordinary composition, with the amount required on a 1000-kcal. low-protein diet and then compare the corresponding amounts for a person weighing 45 kg. (Table I). In calculating the fluid requirements the assumption is made that the fluid lost from the body *via* the lungs and skin is recovered by recondensation and only the urinary volume need be replaced by supplementary fluid.

TABLE I.—*Weight of Food, Fluid, Oxygen and Carbon Dioxide Absorbent Required per Day by (A) a 75-kg. Man at 2500 kcal./24hr. and Unrestricted Fluid. (B) Restricted Calorie and Fluid Intake, Assuming no Reduction in Metabolism. (C) and (D) Proportional Values for a Person Weighing 45 kg.*

	A	B	C	D
FOOD				
Calorific value, kcal./24 hr. ..	2500	1000	1600	650
Mass, kg./24 hr. (based on 5000 kcal./kg.)	0·5	0·2	0·3	0·15
WATER (to balance urine output), kg./24 hr.	1·5	0·5	1·0	0·3
OXYGEN				
l.(at S.T.P.)/24 hr.	510	510	330	330
Gross mass at 1:1 storage efficiency, kg./24 hr.	1·5	1·5	1·0	1·0
CARBON DIOXIDE				
Volume produced, l. (at S.T.P.)/24 hr.	430	430	275	275
Mass of carbon dioxide absorbent, kg./24 hr.	0·5	0·5	0·3	0·3
Total mass for maintenance, kg./24 hr.	4·0	2·7	2·6	1·7

Under the heading of maintenance one must include the weight of oxygen consumed together with the apparatus for supplying it, and the weight of chemical absorbent for removing inhaled carbon dioxide from the cabin atmosphere. The efficiency of liquid oxygen systems today is of the order of 1:4 as compared with about 1:4 in the days of compressed oxygen and 1 kg. of carbon dioxide absorbent (lithium hydroxide) absorbs 860 l. carbon dioxide.* Hence 2 kg. mass must be allowed for each 1 kg. of oxygen absorbed by occupants

* For periods longer than 9 days, a carbon dioxide regenerating system as used in submarines would be needed. In such a system, carbon dioxide absorbed from the air in the atmosphere is regenerated by heat and extruded into the sea.

TABLE II.—*Carbon Monoxide Excretion in Non-Smokers and Permissible Concentrations in the Atmosphere at Sea Level and at* 18,000 *ft. In a* 5-*m.*^{3} (180-*ft.*^{3}) *Space Capsule with Two Occupants These Limits Would Be Reached in* 12 *and* 3½ *days Respectively*

Blood level (non-smokers)	0·2 ml. %
Excretion *via* lungs	20 ml./24 hr.
Permissible limit in air at sea level	0·01%
Permissible limit in air at 18,000 ft.	0·003%

TABLE III.—*Comparative Masses* (*kg.*) *for Personnel and* 7 *days' Maintenance.* (*A*) *Body Mass* 75 *kg., Metabolism and Food Intake* 2500 *kcal./24 hr.* (*B*) *Body Mass* 45 *kg., Metabolism* 1600 *kcal./24 hr. Food Intake Restricted to* 650 *kcal.*

	A	B
Personnel	75	45
Maintenance	28	12
Total mass	103	57

of the space cabin and 1 kg. mass for each 860 l. of carbon dioxide produced (carbon dioxide, being an end-product of metabolism, does not of itself increase the total mass of the cabin).

Another gas which must be taken into consideration is carbon monoxide. Apart from smoking, small amounts of carbon monoxide are produced endogenously in the body and excreted *via* the lungs. Eventually the carbon monoxide derived from this source, quite apart from the contribution from smoking, would reach poisonous concentrations in a space cabin unless removed by catalytic oxidation (Table II).

Proceeding to Table III, it can be seen that the mass economy that could be achieved by food and fluid restriction of moderate degree and choice of small personnel is such that it would be possible to carry a crew of two persons instead of one. This raises the question whether it is better to employ one person maintained in the best possible condition without restriction of oxygen, food or fluid, or a crew of two on restricted maintenance.

The answer to this question will depend on the personality of the crew, the duration of the journey and the number and complexity of observations to be carried out. If experience of the kind gained on Mt. Everest is any guide, the psychological advantage of companionship would be worth very considerable sacrifices in physical comfort.

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SPACE TRANSPORT OF LIFE IN THE DRIED OR FROZEN STATE*

By A. S. PARKES,† C.B.E., Sc.D., F.R.S., and AUDREY U. SMITH,† M.B., B.S., D.Sc.
(Communication from the Medical Research Council)

ABSTRACT

Modern biological knowledge of the resistance of living organisms to freezing, drying, and lack of oxygen, is discussed in the light of some of the conditions likely to be encountered in space and on the planets.

LIFE, in the sense of self-propagating matter, as we know it on Earth, depends essentially on a cycle involving water, oxygen, carbon dioxide and fixed nitrogen, and a temperature at which their interaction is possible. In lower organisms the chain of events is often arrested temporarily by drying or cooling without permanent damage to the system. Moreover, many lower organisms and most plants take the precaution of producing spores or seeds which have a very low water content and a negligible respiration rate, and thus have a high resistance to cooling, drying and lack of oxygen. There are well-known examples of spores and seeds remaining viable for hundreds or even thousands of years under highly adverse conditions.

Biologically, therefore, there should be no difficulty in landing spores, seeds, or desiccated organisms in good condition on another planet, provided that overheating and irradiation effects could be avoided. Further, some of the photosynthesizing organisms, which take in an excess of carbon dioxide and put out an excess of oxygen, might even become established on Mars, where it seems they would find some water, an abundance of carbon dioxide and a summer temperature compatible with earthly life. The chances would be particularly good in the case of some of the xerophytic plants, especially the symbiotic lichens, which to some extent provide their own micro-climate. It has, in fact, often been pointed out that the apparent vegetation on Mars, if similar to anything found on Earth, has possibly evolved along the lines of the lichens.

The problem of establishing animals, which depend essentially not only on plant food but on a supply of

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free oxygen, on other planets is very different. Lichen-like vegetation might supply the basic plant food, but the scarcity of oxygen, even on Mars, must mean that animal life in the sense of self-propagating matter ultimately dependent on plant food, if it has evolved at all, must have done so along lines unknown on Earth. The establishment of earthly animal life on the planets, especially in its more complex forms (*e.g.*, mammals), would require the provision of micro-climates in which oxygen tension, humidity, and probably also temperature, were adjusted.

The biological problem of transporting any of the higher forms of animal life to the planets is also formidable. Clearly a state of suspended animation (anabiosis) in which food, water, and oxygen requirements were abolished would be highly advantageous, and here we can be guided by a rapidly expanding body of knowledge on the long-term preservation at low temperatures of animal organisms and of their essential germ cells. Alaskan and Siberian insects provide good examples of anabiosis induced in nature by cold and persisting for many months, and under experimental conditions there are now reports of moth larvae remaining viable after being frozen and stored in liquid air. Again, inter-tidal molluscs, necessarily exposed to air temperatures at low tides, are in some regions remarkably tolerant of being frozen and thawed twice a day during the winter.

With vertebrate animals, even with the cold-blooded ones which can adjust their body to a wide range of temperatures above freezing point, the situation is quite different. There is no evidence that fish or frogs under natural conditions can survive the conversion of all their body water to ice. Stories of fish and frogs remaining viable after being found frozen solid in blocks of ice probably derive from the fact that a fish, with its lower freezing point, could remain unfrozen in a block of ice and would live until it died of oxygen lack.

The young or hibernating warm-blooded animal has something in common with the cold-blooded animal in that its body temperature can be reduced to a few degrees above 0° C. without damage. It has even been reported that the hibernating bat may supercool below zero in hard winters. In all these cases, however, heart-beat and respiration still proceed slowly, so that the state is not one of suspended animation. Moreover, there is no evidence that the cold-blooded vertebrate, or the young or hibernating warm-blooded animal, has any dispensation from the damage caused by conversion of body water to ice. In adult non-hibernating mammals the position is still more difficult because heart-beat and respiration cease when the body temperature is reduced to about 15° C., so that during cooling the animal must spend longer in the dangerous stage between loss of heart-beat and respiration and reaching 0° C. In fact, until recently it was supposed that if the body temperature of a rat or a dog were artificially reduced below about +15° C., at which temperature heart-beat and respiration cease, death was inevitable. This is now known not to be so, and by special methods mice, rats, and dogs have all been revived from deep body temperatures just above 0° C. after cessation of heart-beat and respiration for an hour or more. Recovery is usually complete and, remarkably, tests on resuscitated rats have shown no impairment of memory or learning ability following the severe anoxia.

In the case of the hamster, a potential hibernator, which can be handled more easily in the range of body temperatures above freezing point, the experiment has been pushed further and body temperature taken below zero by immersion in a bath at −5° C. In these circumstances one or other of two things happens; the animal may start to freeze, or it may supercool. In the freezing animal, body water begins to be converted to ice in the superficial tissues, in which case the deep body temperature drops only very slowly below the freezing point of the blood, −0·6° C. Such animals have been resuscitated undamaged after being below freezing point for up to one hour, at which point some 50% of the body water had been converted to ice. In the supercooling animal, the body temperature is not maintained by the latent heat of crystallization of water and the temperature falls rapidly to that of the surrounding bath. The supercooled state may be terminated by the sudden crystallization of body water which results in a rapid rise of body temperature to its freezing point, an event which is very dangerous to the animal. Otherwise, the supercooled state is a benign one from which animals can be revived in perfect condition. It must be emphasized, however, that the partly frozen or slightly supercooled animal is in a highly unstable condition and that much lower temperatures will be required to arrest biochemical and physical changes entirely and so obtain a stable state in which the animal can be preserved indefinitely. The biologist is thus not within sight of obtaining long-term suspended animation in warm-blooded animals, or any other vertebrate, but it would be a mistake to suppose that he never will. In man, body temperature is now commonly reduced to about +28° C. for surgical purposes, but at this stage heart-beat and respiration are still proceeding slowly. Science fiction notwithstanding, the prospect of suspending animation for indefinite periods in man by freezing him is remote. When it becomes practicable will it help the exploration of space? Possibly: to carry a proportion of the crew of a spaceship in a state of suspended animation would reduce oxygen and food requirements, and ensure replacements for the animate members who on the longer journeys might begin to suffer from old age, if nothing worse.

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AVOIDING THE RADIATION BELT*

By A. E. SLATER,† M.A., M.R.C.S., L.R.C.P., Member of Council

ABSTRACT

The hazards of the van Allen radiation belts are discussed and attention is drawn to the fact that once every day the ecliptic is inclined 35° to the magnetic equator, thus providing the possibility of making interplanetary journeys without passing through the dangerous zone by a suitable choice of launching time. Conditions for the lunar voyage are indicated.

ON 31 January, 1958, the *Explorer I* satellite was launched with 10·83 lb. of instruments contained in a cylinder of 6 in. diameter and, in the words of Dr. Wernher von Braun,[1] "from this inauspicious springboard there developed a major scientific discovery in physics," namely a radiation belt round the Earth which appears to present a far greater hazard to human space travel than do cosmic rays, formerly regarded as the most troublesome form of radiation likely to be encountered.

Explorer I just reached the base of the radiation belt at about 1000 km. above the Earth's surface, and the hope was then expressed that the phenomenon was quite localized and need not cause much worry to space travellers. However, this optimism was shattered when the *Explorer III* satellite went up to greater heights and revealed that the belt extended to at least 2800 km. with no sign of its intensity falling off with distance. Then *Explorer IV* was launched on 26 July, 1958, in time for an analysis of the first two weeks' data from it to be presented by Dr. James Van Allen *et al.*[2] at the IXth International Astronautical Congress in Amsterdam during August, 1958.

The state of knowledge about the extent of the radiation belt at this time, as given by A. H. Hibbs,[3] was that it existed "at altitudes above approximately 1000 km. for regions between 30 deg. north latitude and 30 deg. south latitude"‡; and that these limits were magnetic latitudes was confirmed by Van Allen's statement[2] that the data were "consistent with symmetry about the eccentric magnetic dipole."

It is the main purpose of this paper to draw attention to a fact which appears to have been overlooked in every discussion the author has so far seen or heard on the possibility of avoiding the hazards of the radiation belt. This fact is simply that the plane of the magnetic equator is inclined approximately 11½° to that of the geographical equator, and the latter, in turn, is inclined 23½° to the plane of the ecliptic. Once every sidereal day, therefore, these two figures add up so that the ecliptic is inclined 35° to the magnetic equator, and therefore lies 5° outside the 30° limit of the dangerous region of the radiation belt. And since practically all interplanetary journeys of the future will be made within 5° of the plane of the ecliptic, they could be timed to miss the dangerous region even if the vessel leaves the Earth vertically along a line joining its centre to that of the target planet.§

Fig. 1 shows the position of the geomagnetic equator where it cuts the Earth's surface, assuming the so-called "eccentric dipole field" of the Earth. This type of assumed field gives the best "fit" to the actual magnetic field in the space around the Earth, which determines the position of the radiation belt. The assumed "eccentric dipole" passes to one side of the actual centre of the Earth, missing it by about 340 km. (210 miles), and in consequence the base of the belt should be highest (about 1340 km. or 830 miles) over the Central Pacific and lowest (660 km. or 410 miles) over Africa.**

Magnetic latitudes 30° N. and 30° S. are also shown, and a remarkable coincidence is at once apparent: Cape Canaveral lies only 2° east of the longitude in which the magnetic equator is furthest south, so that, although its geographical latitude is only 28½° N., its magnetic latitude is nearly 40° N.: consequently a vertical line passing through it lies 10° outside the dangerous part of the radiation belt. Similarly, Woomera, in latitude 31° S., is only 16° east of the longitude in which the belt is furthest north, and misses the 30° limit by about 12°. Overhead of both places, the base of the radiation belt is, for the reason already mentioned, a little above its average height; this effect is more marked at Woomera.††

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* Paper presented at the Space Medicine Symposium, 16–17 October, 1958.

† Dell Farm, Whipsnade, Dunstable, Bedfordshire.

‡ *Note added in proof.*

Since the Space Medicine Symposium was held, the radiation belt has been mapped in much greater detail with the help of further satellite and lunar rockets; but S. F. Singer,[4] more than a year later, still stated that "only the inner belt in the altitude region 1000 to about 6000 km. up to magnetic latitude 30° presents any problem" as regards danger to human travellers.

§ *Note added in proof.*

Since this paper was read at the Space Medicine Symposium, expert writers have continued to assume that the danger cannot be avoided except by taking off from the Polar regions. For example, Prof. H. S. W. Massey has written[5]: "Along the way to the Moon the vehicle passes through the region of intense radiation which extends out from a height of about 500 miles above the Earth." And Dr. H. J. Schaefer[6] has taken it for granted that a "radial shot" along a line joining the centres of the Earth and Moon would necessarily pass through the centre of the radiation belt.

** *Note added in proof.* This has since been confirmed.[7]

†† *Note added in proof.*

Where, about a year after this Symposium, a Black Knight rocket failed to reach the belt for this reason.[7]

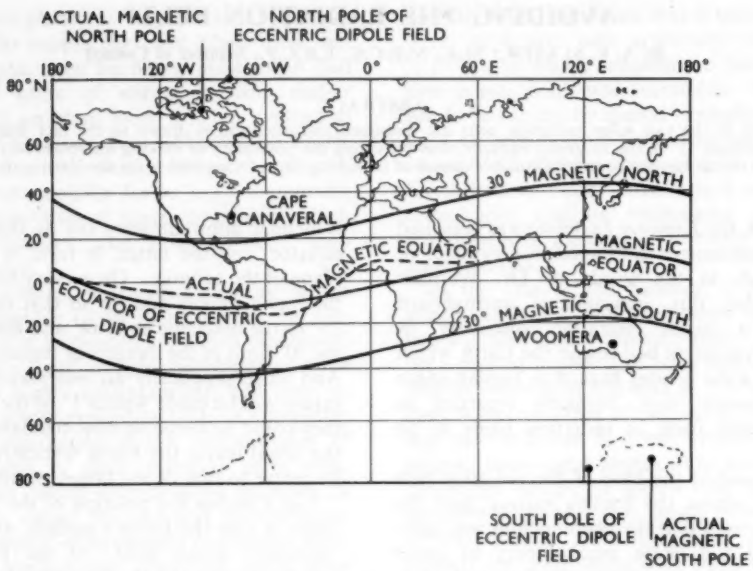

FIG. 1. Eccentric dipole field of the Earth

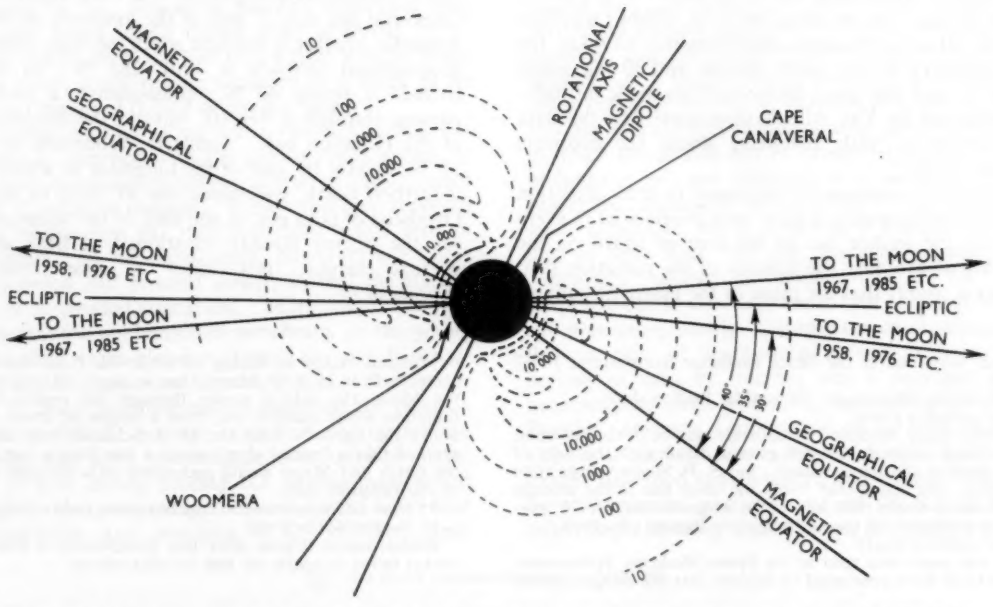

FIG. 2. Section through Earth and radiation belt at time of maximum deviation of magnetic equator from ecliptic. Figures on contours of radiation belt give hits/second on detecting instrument, but core of inner zone (protons) is an order of magnitude more dangerous than that of outer zone (electrons).

The actual magnetic field at the Earth's surface, it should be mentioned, is somewhat irregular: in particular, the magnetic equator deviates southwards over Brazil, and northwards over Africa, from its position as calculated from the eccentric dipole.

Fig. 2 shows a section through the Earth and the radiation belt, in a plane at right angles to the planes of the ecliptic and the geographical and magnetic equators, at a time when the magnetic equator is at its greatest inclination to the ecliptic. The diagram demonstrates the main theme of this paper, and consideration of the position of the Earth's axis, in relation to its orbit round the Sun, shows that the most favourable time to start an interplanetary voyage is around the time of the autumn equinox (*i.e.*, September in the Northern Hemisphere and March in the Southern) if the route follows a straight line drawn from the Earth's centre in the direction of its motion round the Sun. The vehicle would then by-pass the centre of the inner belt about 3 minutes, and of the outer belt about 33 minutes, after take-off.*

A launch along the usual type of curved track should take the vehicle past the centres of both belts in under an hour, and during this time it should be able to keep clear of the 30-degree limit before the rotation of the dipole about the Earth's axis brings the ecliptic once more inside the danger zone. In this case, to get the desired additional push from the Earth's rotation, the launch would have to be made at around the Winter solstice, shortly before midnight.

Particularly interesting is the situation regarding a take-off for the Moon, the plane of whose orbit is inclined 5° to that of the ecliptic, and rotates round the latter once every 18 years 10 days. Just now, at the time of this Symposium, its inclination to the equator is at a minimum, so it skirts the 30° limits of the radiation belt even at the favourable time shown in the diagram, and is immersed in it at all other times of day. In the year 1967, however, and every 18 years thereafter, the plane of the Moon's orbit will miss the hazardous region of the belt by 10°, once a day, and so can a lunar vehicle travelling in that plane. Here, again, if it is desired to reach the Moon at a particular phase of its monthly cycle, the launch must be made at the correct season of the year; otherwise any time of year will do.

At the 1958 I.A.F. Congress, Singer[4] proposed an explanation of the presence of the radiation belt: he suggested that it consisted of protons formed from the disintegration of neutrons which, in turn, had been set free by cosmic-ray bombardment of the upper atmosphere.†

Singer[4] has suggested four ways of counteracting the obvious hazards of proton bombardment:

(1) *Launches could be made from the Polar regions;* the purpose of the present paper is to show that this is unnecessary.

(2) *It is not necessary to surround the traveller completely with shielding, which would then be impracticably heavy. Since all the protons move approximately in a plane at right angles to the magnetic lines of force, a ring of shielding, weighing only about a tenth as much, should suffice if maintained in this plane.*

(3) *The incident radiation could be turned away by putting a coil around the vechicle so as to create a small-scale dipole field.* However, the power required would be "quite stupendous."

(4) *Launching artificial satellites to absorb the protons, which move at high velocity along spiral paths within the belt.* A satellite of 10 metres diameter could, Singer estimated, sweep up virtually all the protons in about a year, or twelve such satellites could do it in about a month.

On hearing this, one was at once reminded of the Walrus and the Carpenter who "wept like anything to see such quantities of sand," and particularly of the Walrus's proposal[8]:

'If seven maids with seven mops
Swept it for half a year
Do you suppose,' the Walrus said,
'That they could get it clear?'
'I doubt it,' said the Carpenter,
And shed a bitter tear.

But there is an essential difference between this project and Singer's: in the latter, the "sand" flings itself on to the "mop."

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* See Schaefer.[6]

† *Note added in proof.*
This theory is now widely accepted as the cause of the inner of the two zones into which the radiation belt was later found to be subdivided; the outer zone, however, is now generally believed to consist of electrons and to originate from particles shot out from the Sun. Although these electrons are comparatively harmless, Schaefer[6] has pointed out that their impact on the structure of a space vessel would give rise secondarily to X-rays. However, so little was known about the precise medical hazards of the radiation belt at the time of the Symposium, that they were not discussed in this paper.

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PROCEEDINGS OF THE SPACE MEDICINE SYMPOSIUM

The first symposium on space medicine to be held in Great Britain was organized by the Society to coincide with the twenty-fifth anniversary of its foundation. The symposium took place in the Great Hall, B.M.A. House, Tavistock Square, London, W.C.1, on 16 and 17 October, 1958, details of the programme being given below (the papers presented are reproduced on pp. 279–323 of this issue of the *Journal*, some of them necessarily in an abbreviated form).

A small exhibition was also on display in the Great Hall. The R.A.F. Institute of Aviation Medicine provided large models of the Institute's human centrifuge and wind tunnel. Atmosphere-conditioning equipment was exhibited by the British Oxygen Co. Ltd., and Normalair Ltd.

The proceedings concluded with the Twenty-fifth Anniversary Celebrations Dinner, held at the Waldorf Hotel, Aldwych, London, W.C.2, on the evening of Friday, 17 October.

Organizing Committee

Mr. G. V. E. Thompson (*Chairman*) Dr. A. E. Slater (*Secretary*)
Dr. B. E. Finch Flt. Lt. J. C. Guignard Dr. J. A. Moyse

PROGRAMME

Thursday, 16 *October: Morning Session*

Chairman: Dr. L. R. Shepherd (Chairman of Council).

Introductory Address, by Dr. L. R. Shepherd.

"Vision and Orientation at Extreme Altitudes," by Sqn. Ldr. T. C. D. Whiteside (R.A.F. Institute of Aviation Medicine). P. 252 of this issue.

"Some Consequences of Weightlessness and Artificial Weight," by Dr. M. P. Lansberg (National Aeromedical Centre, Netherlands). Pp. 285–288.

"Human Factors in a Space Cabin, with Special Reference to Weight and Economy," by Dr. L. G. C. E. Pugh (Medical Research Council). Pp. 317–319.

"The Physiological Effects of Transient Mechanical Forces: A Review of Their Relevance to Astronautics," by Flt. Lt. J. C. Guignard (R.A.F. Institute of Aviation Medicine). Pp. 290–292.

Thursday, 16 *October: Afternoon Session.*

Chairman: Dr. J. B. Parry (Air Ministry).

"The Man-Machine System in Space Vehicles," by Cmdr. George W. Hoover (U.S. Office of Naval Research). Pp. 304–310.

Round Table Discussion on Cmdr. Hoover's paper by members of the U.S. Office of Naval Research Instrumentation Team. Not reproduced in the *Journal*.

"Impairment of Human Performance in Control," by Dr. K. F. Jackson (R.A.F. Institute of Aviation Medicine). Pp. 301–303.

"The Effects of Sensory Impoverishment, Confinement and Sleep Deprivation," by C. Cunningham (Air Ministry). Pp. 311–314.

Friday, 17 *October: Morning Session.*

Chairman: Dr. H. A. Clegg (British Medical Association).

"Effects of Prolonged Exposure to Positive *g* Loadings on the Pulmonary Gas Exchange," by Dr. Hilding Bjurstedt (Laboratory of Aviation and Naval Medicine, Stockholm). Pp. 288–289.

"Man's Thermal Environment during Interplanetary Flight," by Flt. Lt. J. Billingham (R.A.F. Institute of Aviation Medicine). Pp. 293–297.

"Heat Exchange between Man and His Environment on the Surface of the Moon," by Flt. Lt. J. Billingham (R.A.F. Institute of Aviation Medicine). Pp. 297–300.

"Space Transport of Life in the Dried or Frozen State," by Dr. A. S. Parkes and Dr. Audrey U. Smith (National Institute of Medical Research). Pp. 319–320.

Friday, 17 *October: Afternoon Session.*

Chairman: Professor E. P. Sharpey-Schafer (St. Thomas's Hospital).

"Some Blast Studies with Application to Explosive Decompression," by Dr. Carl-Johan Clemedson (Research Institute of National Defence, Stockholm). Pp. 279–285.

"Some Problems of Spaceflight Feeding," by S. W. F. Hanson. Pp. 314–316.

"Avoiding the Radiation Belt," by Dr. A. E. Slater (Member of Council). Pp. 321–323.

This two-day conference was a notable event in the history of the Society, being the first symposium to be sponsored independently by the Society. Bearing this fact in mind, and the specialized nature of the subject, it was very well attended (about 80 persons registered for the symposium and nearly 200 attended the Dinner). These figures were of course greatly exceeded in the two subsequent conferences (the Commonwealth Spaceflight Symposium and the Tenth International Astronautical Congress).

Preliminary consideration has been given to the holding of the Second Space Medicine Symposium. An announcement will be made in the *Journal* when tentative dates and venue have been chosen.

SOME NUTRITIONAL PROBLEMS OF MANNED SPACEFLIGHT*

By MICHAEL H. BRIGGS,† M.S., F.R.A.S., Fellow

ABSTRACT

A discussion of the most suitable type of diet for consumption by the crew of a spaceship is presented. Methods for the recovery of water and other substances from human excreta are reviewed and the problems of algal culture from these extracts are outlined.

I. INTRODUCTION

THE occupants of a spaceship will be within a sealed cabin. Into this cabin must be supplied all the essential nutrients, while the waste products of metabolism, carbon dioxide, urine, and fæces, must be removed. These basic conditions present considerable nutritional problems on many levels, some of which have been considered in previous papers by Adams,[1] Ebbs,[2,3] Fenno[4] and Taylor.[5] In the present paper the discussion will be limited to a consideration of the most suitable type of diet, the recovery of materials from excreta, and the use of microorganisms to balance a closed system.

II. NATURE OF A SUITABLE DIET FOR SPACEMEN

It is apparent that under the practically zero conditions of gravity within a spaceship most of the traditional human foodstuffs become unsuitable. Ingestion of food itself is not a serious problem as once inside the mouth the closed lips and controlled movements of the tongue are sufficient to ensure satisfactory swallowing and passage of the bolus down the œsophagus by peristalsis. Pre-ingestion, however, offers many problems and presents limitations as to the type and consistency of suitable foods. Liquids will be unmanageable unless in a special container, for pouring and drinking from an open vessel will not be possible. The most convenient type of liquid container is some form of flexible tube (like a large tooth-paste tube) fixed with a mouthpiece of plastic tubing along which the liquid can be passed directly into the mouth by manual pressure on the container. Tube-type feeding of this sort has already been tested at the Aero-Medical Laboratory, Wright-Patterson Air Force Base, Ohio, U.S.A.[2] It appears, incidentally, that feeding by this method may be possible even when the subject is within an enclosed suit if a suitable type of sealed entry for the mouth-tube is constructed into the helmet of the spacesuit. This will obviate the otherwise considerable problem of feeding men away from the spaceship, say on the lunar surface.

Feeding containers will be suitable for the consumption of both simple liquids and emulsions. It is, however, obviously undesirable that the space diet should be totally liquid, and solid food of some type appears to be a necessity. Limitations of gravity, storage, and sterilization indicate that the most suitable type of solid food is a solid block, though the ordinary sandwich is not impossible.

It would appear that by these means a space diet could be made up of fairly familiar foodstuffs. This is desirable, as unfamiliar feeding habits—such as pilled concentrates or intravenous feeding—would produce undesirable psychological states within a short time. Moreover by a careful selection and pre-preparation of the meals, monotony can be avoided and eating should offer the spaceman an interesting break from what will otherwise probably be a most uninteresting and dull voyage.

Although these methods of food preparation and feeding are a desirable basis, it is necessary that some alternative should be available. It is likely that the initial stages of any spaceflight will be accompanied by nausea. In the absence of any experimental evidence to the contrary, it is wise to assume that this will last for a considerable part of the trip. In a state of nausea it is possible that the eating of more or less ordinary foods will be impossible and hence pilled concentrates should be available and should contain the essential nutrients (*i.e.*, amino acids, monosaccharides, vitamins) in a readily absorbable state. Such pills might also contain some anti-nausea agent.

Although the type of diet and method of feeding are simple to decide, the chemical nature is not. The human requirement of most nutrients is now well known and Table I lists the recommended[6] daily requirements. It will be assumed that the occupants of a spaceship will show the same requirements as on Earth, though it is a remote possibility that the unusual conditions of spaceflight may produce changes in the physiology of either the human body or the intestinal flora. Either type of change could result in an altered nutritional requirement for one or more factors. Assuming, however, that such changes will not occur, a number of diets containing the known nutritional factors and of the suitable type can be worked out. The basic materials which immediately suggest themselves are soups, broths, chocolate, dried fruits, fortified bread, meat extracts, etc.

Considerations of weight and volume of the foodstuffs must also be of prime importance. For example, it is apparent that fresh or frozen foods of a perishable nature which require refrigeration are unsuitable owing to the weight and size of the refrigeration equipment. Foods

* Manuscript received 15 January, 1960.

† Department of Chemistry, Victoria University of Wellington, New Zealand.

TABLE I.—*Human Daily Nutritional Requirements**

Body weight, lb.	Nutrient								
	Protein, g.	Calcium, g.	Iron, mg.	Thiamine, mg.	Riboflavin, mg.	Niacin, mg.	*L*-ascorbic acid, mg.	Vitamin A, I.U.†	Total Calories
80	40	0·40	6	0·60	1·1	6·0	30	2600	2150
100	50	0·45	6	0·70	1·2	7·0	30	3200	2350
120	55	0·55	6	0·80	1·3	8·0	30	4000	2650
140	60	0·65	6	0·85	1·4	8·5	30	4600	2850
160	70	0·75	6	0·90	1·5	9·0	30	5300	3050

* Canadian standard for male subject of moderate activity. † International Units of β-carotene. For preformed Vitamin A, the values are divided by four.

requiring conventional heating are unsuitable for a similar reason. However, foods contained in sealed sterile containers, vacuum dehydrated products, dehydrated precooked meals, and perishable foods preserved by irradiation all offer apparently useful methods of storage without inconvenient extra weight or bulk.[7]

The immediate future for space travel is unquestionably the exploration of the Moon, with perhaps the establishment of a permanent orbital space station around the Earth. Voyages such as these will necessitate several days, or a few weeks, within spaceships.[8] Trips to other planets, however, will involve voyages of several years. It is obvious that the nutritional problems presented by these two types of journey are quite dissimilar. In the shorter voyages it is reasonable to suppose that sufficient food can be conveniently carried on the spaceship. Considerations of weight make it improbable that sufficient food can be carried for the longer type of journey. The rest of this paper will consider problems of the recycling of organic material within the closed system of the spaceship and of the possibilities of food synthesis.

III. RECOVERY OF MATERIALS FROM EXCRETA

The most limiting nutrient within a spaceship is water. An average man consumes about 2.5 l. (*i.e.*, 2.5 kg.). daily. This, allowing for a small amount of wastage and excess, amounts to almost 1 tonne in a year. Hence a crew of four would consume 4 tonnes each year; an amount that is an appreciable fraction of the total mass of the spaceship. Such a situation is unthinkable, as no allowance has been made for washing and other essential uses of water. It is apparent that some efficient means must be devised to recover the water from the excreta of the spacemen.

Water is excreted from the body in four different ways, sweat, vapour in expired air, urine, and fæces. Recovery from the first two excretions is comparatively simple. Sweat is retained largely by the underclothing, though some evaporates as vapour. On washing the clothing the total water can be recovered together. Water vapour in the air will be removed, as the spaceship atmosphere will be constantly replenished and recirculated. If passed over some deliquescent compound the water will be removed and eventually a further solution will be formed for recovery. Hence the problem of water recovery resolves to two problems. First, the recovery from the liquid wastes, including the washing water, the solution from the air filters, and the urine; second, recovery from the solid fæces.

Separation of pure water from the liquid wastes presents an interesting problem. There appear to be only two alternative methods, distillation or ion-exchange chromatography. It is questionable which of these methods will provide the most suitable alternative. Distillation, of course, implies the use of some type of heating. This could be provided electrically by solar batteries, or by direct sunlight, using the difference in illumination on opposite walls of the spaceship. In the latter case the evaporation and condensation tubes would have to be constructed into the walls of the vessel. This is probably undesirable. The second possibility, the use of ion exchange chromatography, presents a more convenient system, but is not without its disadvantages. A combination of suitable resins, perhaps treated with antibiotics, would definitely provide a source of drinkable water, but the resins, unfortunately, will not last indefinitely and even if carefully treated and eluted with solvents at intervals their lifetime is limited. It would be a matter for controlled experiment to determine the weight of resin required to provide satisfactory fractionation of the liquid wastes for the period of the journey. A supply of several kilograms of resin would probably be sufficient for a trip of several days (*i.e.*, to the Moon), but an interplanetary voyage might require prohibitively large amounts. This is a topic which will have to be decided from future experiments. For the purposes of this discussion, however, it is apparent that a method of water recovery from liquid wastes will be possible.

The recovery of water from the solid fæces, therefore, will present little difficulty. An obvious method would be to homogenize the fæces with added water and then run them through either the distillation apparatus or the ion exchange columns. Dry solid waste could be recovered in either case without too much difficulty. Alternatively the fæces could be dried directly in a special oven and the water so produced collected by a cooling system. In this manner the fæces would be sterilised as well as recovered.

Whatever method of water recovery is used some solid material will accumulate. This will be largely from the fæces, though some salts and other compounds will be derived from the urine and washing water. It is therefore worth considering the chemical nature of these residues and possible use to which they can be put.

The composition of the fæces is rather varied. According to Hawk *et al.*[9], fæces are made up of residues from the intestine after the digestion and absorption of the food, some products of intestinal secretion, epithelial debris, and the products of bacterial growth and decomposition. On an ordinary diet an adult male subject will excrete daily between 110 and 170 g. with a solid content of 25 to 45 g. Thus with a crew of four, solid residues from the fæces alone will amount to some 100 to 180 g./day, or between 36.5 and 65.8 kg. annually. This material will be composed of lipids, proteins, free amino acids and peptides, some vitamins, a mixture of carbohydrates, bile pigments and their decomposition products, phosphates and other salts of calcium, iron and other metals, as well as a variety of other organic compounds. Some of these substances are of use for human food, but could not be used unless separated from the remainder. This separation, however, would be exceedingly complex and it is unlikely that a spaceship could carry the equipment required. An alternative use for the material, that it be used as nutrients for algae, has been previously considered by Bowman.[10] Although the material certainly contains many of the essentials for algal growth, it also contains products which are toxic and some separation would be required. This might be achieved by a further system of exchange resins, though the problem is complex and requires a considerable amount of experimental investigation. Should it prove impossible to use this material for either human or algal nutrition only two alternatives remain. The material could simply be ejected from the spaceship, or it could be treated with a mixed culture of bacteria to produce materials that could be used as nutrients. This latter alternative will be considered in the final section.

IV. THE USE OF MICROORGANISMS TO BALANCE A CLOSED SYSTEM

Although on a short trip it is probable that sufficient food and air can be carried, the longer voyages of several years present the problem of efficient recovery. The most suitable method of converting expired carbon dioxide into oxygen and also providing at least partially some nutrient material, appears to be by the use of a photosynthetic microorganism, such as green algae, grown in mass culture. Methods and progress in the mass culture of simple organisms of this type have already been the subjects for a number of previous reviews[11–13] and the details will not be repeated here. It will be assumed that the mass culture of algae is possible under the conditions within a spaceship where the main carbon source of the plant is expired carbon dioxide and light is provided electrically, probably by a solar battery.

Approximately 2¼ kg. algae can produce sufficient oxygen to support one man and remove his expired carbon dioxide. Therefore with a crew of four, about 9 kg. algae would be required. This algae would have to be cultured on some type of constant flow system so that the mass of plant material remained constant, but some was always being removed. The solid material of algae has the approximately constant composition of 50% protein, 25% fat, 15% carbohydrates, and 10% mineral ash. Carotenes, B vitamins, and ascorbic acid are also present. It is apparent that this material can be used to supply part of the spaceman's diet, probably in the form of broths. Some of the carbohydrate will be cellulose and hence indigestible.

A diet consisting solely of stewed algae would be both nutritionally and psychologically unsuitable. Additional nutrients would be required in some solid form. Moreover, as was discussed above it is unlikely that the mineral and other requirements of the algae can be supplied completely from the solid residue recovered from human excretion. Additional nutrients would have to be added to the algal culture, though these would be few. The greatest problem appears to be a method for converting the solid human residues into a nutrient medium suitable for algal culture. This might be achieved by bacterial fermentation of the residues and then a partial separation by chromatography to remove the toxic products. Such matters open up many questions that are at present unaswerable.

To depend upon an algal culture completely for food and air will be dangerous for the conditions of spac, particularly the radiation, may well alter the physiological properties of the culture by mutation. Spare preserved culture will have to be carried for such an eventuallty.

VI. CONCLUSION

Manned spaceflight presents a large number of nutritional problems. A satisfactory diet will have to contain the essential nutrients supplied in a form suitable for consumption under the low gravity conditions of a spaceship. On voyages lasting several years food supplies will probably have to be supplemented by algae cultured within the vessel. The supply of nutrients to the algae from solid material recovered from human excreta presents many problems which are not yet solved. Recovery of water from excreta appears to be possible by several methods.

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THE NEED FOR A U.K. SPACE PROGRAMME

The British Interplanetary Society has drawn the attention of the Government to the urgent need for a United Kingdom Space Programme, and on 2 March, 1960, the following document was submitted to the Prime Minister for his consideration:

A SPACE PROGRAMME FOR THE U.K.

A MEMORANDUM FROM THE BRITISH INTERPLANETARY SOCIETY

Recommendation

A British entry in space activity on a more comprehensive scale than has hitherto been proposed has now become essential, if we are to maintain our position in world technology. Fortunately, in adaptations of Blue Streak and Black Knight, and in facilities such as Spadeadam and the Anglo-Australian Woomera range, we already have the means—and have already made much of the financial provision—for an early impact in a field which represents a marriage of the best in all the fundamental, and applied, sciences.

The main items of the U.K. Space Programme suggested herewith would be as follows:

(*a*) A definite project to develop Blue Streak and a modified Black Knight as a satellite launching vehicle. This would be in addition to the expansion of existing work on satellite tracking and orbit analysis, and a more vigorous prosecution of the project to launch British instruments in the American Scout rockets.

(*b*) A later project to develop improved and more powerful second and third stages for a modified Blue Streak.

(*c*) A detailed feasibility study of communications satellites, including an examination of their commercial and military significance.

(*d*) A gradually developing programme of research on hypersonic winged vehicles and their use for controlled re-entry into the atmosphere.

(*e*) A modest programme on space medicine, *i.e.*, on the problems of man in space.

(*f*) A programme of research and development on new propulsion systems, such as the nuclear rocket and electrical (ion and plasma) rockets, possible synthetic metastable propellants of great energy (based on "active" atomic species), etc. This would be a very long-term programme, developing gradually over the next decade or more.

Arguments in support of the above recommendation, and some further details of cost, etc., are given below.

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1. There has been an apparent official tendency in the U.K. to consider astronautics purely in terms of the physical experiments (*e.g.*, on the ionosphere or cosmic radiation) which can be performed with high-altitude rockets and close-orbit satellites.

   This is unduly restrictive in outlook: such subjects are a small, even though important, part of the whole.

   To emphasise the above point, which cannot be over-stressed, British aviation policy in (say) 1910 could not have been determined merely by considering the influence of the new art on our knowledge of meteorology and surveying.

   Of course, as history has shown, the significance of aviation was quite different and much more far-reaching. In much the same way, astronautics has a much broader significance than merely providing a new outlet for research in certain areas of physics.

2. Mankind is obviously on the verge of entering a long new phase of exploration and development, comparable to the conquests of the oceans and the air, but vastly exceeding these in scope. In this context, the views of historians and sociologists on the lessons of the past are as worthy of a hearing as those of contemporary specialists in science and technology.

What will almost certainly turn out to be a complete revolution in human affairs and progress cannot be ignored by this country.

3. It is fully appreciated that the U.K. cannot possibly hope to compete on equal terms of expenditure, and diversity of projects, with the U.S.A. and U.S.S.R. To assume, however, that we can therefore play no significant part at all would be a betrayal of our national future. The installation of British instruments in American satellites is not, in this context, regarded as constituting, by itself, "a significant part."

   Leaving aside the ultimate implications that space exploration will have for the future of mankind, astronautics presents the most severe present challenge to applied science and technology. Any nation that contributes to it in an important way will derive considerable benefits, both from the direct technical standpoint (in terms of general advances in technology), and also in the indirect non-technical sense.

4. Of the relevant non-technical considerations, the one most often mentioned is national prestige.

   The less-developed countries of the world will tend in future to judge the leading nations at least partly on the basis of their achievements in space. Such judgements will inevitably be reflected in their purchases of technical equipment of all kinds. Should the belief develop that Great Britain is lagging in this most important branch of technology, our status is likely to be undermined at international conferences when relevant problems come up for discussion.

   No one could deny that Russia's success in space has established her as one of the two most advanced countries in science and engineering. Already this has had a marked effect on her position in international trade.

5. Allied to the question of prestige overseas is that of internal morale. This is inseparable from the general sense of national achievement, the stimulus to technology, and the encouragement of new industries, with new products.

   In future, astronautics will play a role, in this respect, equal to and possibly greater than that of aviation during the past fifty years.

6. Apart from the above general considerations, there are important and specific military and civil developments of spaceflight which can be foreseen for the fairly near future.

   These include the use of satellites for military reconnaissance and possibly bombardment, as early-warning posts, navigational aids, and weather observatories, and, perhaps most important of all, for relaying long-distance radio communications. The strategic and commercial importance of the last-mentioned application, in view of our Commonwealth communications requirement and its associated industry, should need no emphasis. The same might be said of possible future developments in rocket-propelled transport vehicles, capable of reaching the Antipodes within a few hours. On the military side, it might be mentioned that the development of any of these devices by a potential enemy would call for defensive means to be at our disposal.

7. It is believed that a truly significant British contribution could be made for an annual expenditure rising within five years to about £20,000,000, and being maintained thereafter at this approximate level. The corresponding deployment of technical manpower would rise to about 1000 graduate scientists and engineers (drawn from a wide variety of disciplines), with supporting technicians, industrial labour, and facilities. This would satisfy the requirements of the programme outlined at the beginning of this memorandum.

   These figures assume the continuance of relevant effort on aircraft and missile (especially ballistic missile) defence projects. If these were curtailed, the budgets specifically for space would need to be greater—as, in that event, they could persumably be. In this connection, it is suggested that a very important consideration is the fact that astronautical projects would enable national techniques and skills to be maintained, against the possibility of any unfortunate future need to reverse disarmament policies.

Conclusion

It is respectfully submitted that an early statement of Government policy, along the lines here advocated, should be made. This should courageously state the long-term objectives, and guarantee reasonable continuity in the effort involved; without the last proviso, workers of an adequate calibre will not be attracted into it.

It is thought that much of the world, especially the Commonwealth and Europe, is awaiting such a lead from us.

If some pronouncement is not made soon, there is a grave danger of contributing still further to the growing tendency for British research and development in the fields of applied science and technology to be associated almost entirely with objectives of immediate military,

commercial, and economic importance. If this state of affairs obtains, then the achievements of our scientists and engineers will become as limited as their objectives, and eventually there will be an inevitable decline in both the level of British applied science and technology and in the morale of the people involved.

The prevention of such a decline can be accomplished if, and only if, a reasonable proportion of our technical effort is expended in areas of a long-term and adventurous nature, one of the most promising of which would be astronautics.

THE BRITISH INTERPLANETARY SOCIETY

24 *February*, 1960.

APPENDIX

The British Interplanetary Society, of 12 Bessborough Gardens, London, S.W.1, was founded in 1933.

It has a present membership of 3500, including many leading workers in the aircraft, missile and nuclear fields, etc.

The preceding memorandum was drawn up to embody the almost unanimous concensus of opinion expressed at two special confidential meetings convened by the Society on 15 January and 19 February. These were attended by the following individuals, all but one or two of whom are leading members of the Society:

Names	*Affiliations*
J. E. Allen	Head of Aerodynamics, Projects and Assessment Dept., Weapons Research Division, A. V. Roe & Co. Ltd.
D. E. Bailey	Head of Assessments Group, Weapons Research Division, A. V. Roe & Co. Ltd.
G. Beardshall	Chief Engineer, Normalair, Ltd.
L. H. Bedford	Director of Engineering, Guided Weapons Division, English Electric Aviation Ltd.
A. H. S. Candlin	Member of Council, British Interplanetary Society.
L. J. Carter	Secretary, British Interplanetary Society.
D. Carton	Lecturer, College of Aeronautics, Cranfield.
D. J. Cashmore	Senior Engineer, Guided Weapons Division, English Electric Aviation Ltd.
A. V. Cleaver	Chief of Rockets Division, Rolls Royce Ltd.
W. T. Fisher	Chief Technician, Bristol-Aerojet Ltd.
K. W. Gatland	Astronautics Editor, *The Aeroplane*.
M. N. Golovine	Managing Director, ATS Ltd., Hawker Siddeley Group.
S. W. Greenwood	Aeronautical Consultant.
W. F. Hilton	Head of Astronautics Section, Advanced Projects Group, Hawker Siddeley Aviation Ltd.
N. H. Langton	Lecturer, National College of Rubber Technology.
P. Masefield	Managing Director, Bristol Aircraft Co. (also President, Royal Aeronautical Society).
G. K. C. Pardoe	Manager, Project Office, de Havilland Propellers Ltd.
The Rt. Hon. Lord Shackleton	House of Lords.
L. R. Shepherd	(U.K.A.E.A.) Head of Research and Development, OEEC "Dragon" Project (also Chairman of Council, British Interplanetary Society)
A. E. Slater	Member of Council, British Interplanetary Society.
B. V. Soames-Charlton	Head of Space Projects Division, Pye Ltd.
G. V. E. Thompson	Editor, *Journal of the British Interplanetary Society*.
H. R. Watson	Technical Director, Sir W. G. Armstrong-Whitworth Aircraft Ltd.
O. H. Wyatt	Senior Project Engineer, Hawker-Siddeley Nuclear Power Co.
Woodrow Wyatt	House of Commons.
P. R. Wyke	Head of Chertsey Research and Development Group, A. V. Roe & Co. Ltd.

CORRESPONDENCE

(In these letters to the Editor, some passages have necessarily been omitted)

Sensory Perception in the Weightless State

SIR,

A. E. Slater[1] in an excellent paper reduced the problem of macular stimulation in the weightless condition to the following statement: "*When the macula lies in the position of minimum stimulation with the otoliths above it, some nerves are still found to transmit impulses to the brain. Are these impulses due to the weight of the otoliths distorting the cell, in which case they would either disappear or be altered in the weightless state? Or are they a 'basic' phenomenon—a kind of spontaneous discharge necessary to keep the nerve in good working order, in which case they would still be present in the weightless state and would give the brain false information?*"

However, spontaneous activity in first-order afferent neurons may not reach cortical levels. Regardless of whether the spontaneous activity is due to the weight of the otolith or whether there is a "basic" phenomenon of spontaneous activity, it may be assumed that such spontaneous impulses depress the sensitivity of signal detection. In the case of paired receptors (such as thermo-receptors or semi-circular canal receptors) where a given stimulus produces acceleration of spontaneous activity in one member and inhibition in the opposite member of the pair, the simple device of reciprocal inhibition can be shown to effectively suppress spontaneous activity.[2] In the case of macular receptors, spontaneous activity produced either by the weight of the otoliths or the inherent rhythmicity of the nerve may be

reduced by a simple threshold device (conjunction) shown in Fig. 1. In Fig. 1, if *A* and *B* are macular

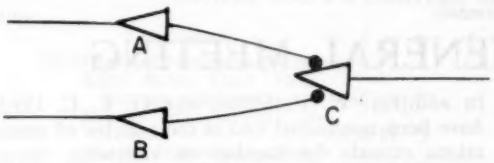

FIG. 1. Low-level "spontaneous" activity originating in the paired macular receptors *A* and *B* would not produce an impulse in *C* unless two impulses arrived simultaneously. High-frequency inputs in *both A* and *B* are required to elicit a significant output in *C*.

receptors (*i.e.*, one from each vestibular apparatus), and neuron *C* has a threshold of 2, then in the notation of McCulloch and Pitts[3]

$$C(t) \cdot \equiv \cdot A(t-1) \cdot B(t-1)$$

Assuming a basic spontaneous frequency of 10 impulses/sec. in each first-order neuron, only a few impulses would arrive simultaneously (*e.g.*, within a few milliseconds) at *C*, generating a "spontaneous" impulse in the second-order neuron. For this reason, only simultaneous stimulations at *A* and *B* producing high-frequency discharges would evoke significant changes in the frequency of *C*.

Very little is known about the precise relationships between any sequential first- and second-order neurons —so that much more experimental neurophysiological information will be required to establish the validity of any such purely theoretical models. However, if such a macular mechanism does exist, then the subgravity and zero-gravity states would not necessarily be expected to produce sensations different from those experienced during exposure to normal terrestrial accelerative loads.

CLYDE M. WILLIAMS.

Radioisotope Unit,
Veterans Administration Hospital,
University Drive, Pittsburgh 40,
Pennsylvania, U.S.A.

22 *May*, 1959.

REFERENCES

1. A. E. Slater, *Ann. Rep. Brit. Interplan. Soc.*, 1952, 342; *J.B.I.S.*, 1952, **11**, 342.
2. C. M. Williams and H. D. Landahl, *Bull. math. Biophys.*, 1958, **20**, 155.
3. W. S. McCulloch and W. Pitts, *ibid.*, 1943, **5**, 115.

SIR,

Dr. Williams' suggestion is ingenious and interesting. I take it that his proposed mechanism would prevent contradictory messages from two different otolith organs from getting through to the brain and causing "space sickness." So it might, if *every* second-order neuron collected impulses from different otolith organs. But for every one that does so, I should have expected a much larger number of second-order neurons each to collect messages from the same otolith organ; otherwise it is difficult to see how the brain could separate the messages from different otolith organs at all, which it would have to do under normal conditions.

A. E. SLATER.

Dell Farm, Whipsnade,
Dunstable, Bedfordshire.

10 *February*, 1960.

Manned Navigation and Guidance in the Solar System

SIR,

I should like to make the following comments on the recent paper[1] by Cashmore and Gordon:

(1) Even for manned missions, I would expect radio command early mid-course guidance to be employed in addition to self-contained systems. It would improve overall reliability, by virtue of the redundancy, and permit early correction of injection (burn-out of last stage) errors so easily.

(2) I agree completely on the question of not attempting to measure vehicle velocity, but using position data with a least-squares fitting procedure. However, I think that the approximation of computing *V* and *D* quantities (p. 50) is an unnecessary and questionable approximation (*see* 5 *below*).

(3) Assuming the vehicle will fly near some precomputed trajectory, why cannot the stellar aberration correction be applied corresponding to this standard trajectory?

(4) It would be inefficient to keep correcting position. and velocity to follow a pre-computed trajectory. As indicated in Section VIII of the paper, a sort of final value control would be more appropriate; the techniques are well known.[2]

(5) There is a lot to be said for employing a stored-program digital computer rather than a D.D.A. There is a tendency this way for boost-guidance. The D.D.A. is not nearly so flexible and grows in size with the complexity of the problem, although as suggested in the paper, there is the possibility of serial operation. It would cope with (*a*) orbit determination by least-squares fitting to measured data, (*b*) computation of the mid-course impulsive corrections, (*c*) high-speed operation for guidance during phases of high acceleration and low-speed operation during free-fall, (*d*) payload date-processing, (*e*) failure detection and built-in logic to improve the overall reliability of the whole vehicle, etc.

Yours sincerely,

MAXWELL NOTON,
Jet Propulsion Laboratory.

California Institute of Technology,
4800 Oak Grove Drive,
Pasadena 3, California, U.S.A.

REFERENCES

1. D. J. Cashmore and C. N. Gordon, *J.B.I.S.*, 1959–60, **17**, 46.
2. M. Noton, "Interplanetary Post-Injection Guidance," *Paper presented at A.R.S. Semi-Annual Meeting, San Diego, California*, June, 1959.

British Interplanetary Society

LIMITED (by Guarantee)

FIFTEENTH ANNUAL GENERAL MEETING

NOTICE IS HEREBY GIVEN that the FIFTEENTH ANNUAL GENERAL MEETING of THE BRITISH INTERPLANETARY SOCIETY will be held in the Kent Room, Caxton Hall, Caxton Street, London, S.W.1, on 15 July, 1960, at 6.30 p.m. in the evening precisely, for the transaction of the business specified in the Agenda below.

AGENDA

1. To hear the Chairman's Address.
2. To receive the balance sheet and accounts for the year from 1 January to 31 December, 1959, and the Auditors' report thereon.
3. To elect five Members of the Council of the Society. In accordance with Article 15, the following will retire at the meeting and with the exception of Mr. Cashmore offer themselves for re-election:
   D. J. Cashmore, D. Hurden, L. R. Shepherd, E. T. B. Smith and G. V. E. Thompson.

   In addition, W. F. Hilton and G. K. C. Pardoe have been nominated and as the number of nominations exceeds the number of vacancies, election will be by postal ballot, which will be circulated to all members beforehand.
4. To receive the Report and Accounts of the Trustees of the Society's Benevolent Fund for the year ended 31 December, 1959.
5. General discussion of the affairs of the Society during the past year.
6. Any other business.

By Order of the Council,

L. J. CARTER,

Secretary.

A member who cannot be personally present at the meeting may appoint by proxy some other person (who must be a member of the Society) to attend and vote on his behalf subject, however, to the proviso that a proxy cannot vote except on a poll.

10th Congress of the International Astronautical Federation
31 August—5 September, 1959

FINANCIAL SUMMARY

	£	s.	d.
1(a) Cash Paid Out			
Opening Reception at St. Ermins	710	9	3
Technical Sessions, Preprints, etc.	1608	11	5
Business Sessions	386	17	6
Space Law Colloquium	73	8	2
Concluding Dorchester Dinner	443	13	2
General Administration	872	17	7
General Congress Entertaining	214	18	0
	4310	15	1
Less Surplus on Excursion	132	15	6
	£4177	19	7

	£	s.	d.
1(b) Cash Received			
Registration Fees	2539	13	0
Wives' Attendance Fees	136	11	6
Springer-Verlag Advertisement	50	0	0
	£2726	4	6

	£	s.	d.
1(c) Summary			
Cost of Congress	4177	19	7
Less Total Receipts	2726	4	6
Loss on Congress	£1451	15	1

	£	s.	d.
2. Loss on Congress financed by—			
Donation from Hawker Siddeley Aviation Ltd.	500	0	0
Amount paid by the B.I.S.	951	15	1
	£1451	15	1

THE BRITISH INTERPLANETARY SOCIETY

BENEVOLENT FUND

Report of the Trustees for the Year ended 31 December, 1959

We hereby present our cash account for the year ended 31 December, 1959:

	£	s.	d.	£	s.	d.
Grant from the Society at 1 January, 1959				250	0	0
Donations received from members in response to our appeal				220	7	1
Grant from the Society as at 31 December, 1959				500	0	0
				970	7	1
Less Disbursements:						
Cost of appeal letters	9	16	0			
One grant to the widow of a late Fellow of the Society	50	0	0			
				59	16	0
Cash at Bank				£910	11	1

Certified to be a true audited copy

L. J. Carter
L. R. Shepherd
G. V. E. Thompson
} *Trustees appointed by the Council.*

The British Interplanetary Society

LIMITED (by Guarantee)

INCOME AND EXPENDITURE ACCOUNT for the Year ended 31 December, 1959

1958 £	Expenditure	£ s. d.	£ s. d.	1958 £	Income	£ s. d.	£ s. d.
	To Office and Management Expenses—				**By Membership Subscriptions and**		
521	Rent, Rates, Light, Heat, Cleaning and Insurance ..	560 3 3		7856	**Entrance Fees**		8277 19 9
104	Salaries and National Insurance	1,270 11 5		395	„ **Donations**		360 11 3
1035	Postage, Stationery and Telephone	883 7 7		1576	„ **Library Subscriptions and Sales of Publications**		2271 4 6
365	Repairs and Renewals ..	63 10 8		552	„ **Advertising Receipts**		573 4 7
297	Publicity and Advertising ..	262 3 8		947	„ **Royalties**		221 0 7
214	Travelling and Entertaining Expenses	276 13 1			„ **Income from Investments—**		
196	Sundry Expenses	282 3 7		35	3½% Defence Bonds ..	35 0 0	
				71	Building Society Deposit Account	80 0 0	
				98	Bank Deposit Interest ..	86 13 8	
							201 13 8
3730							
5632	„ **Publications**		4768 17 1				
864	„ **Expenses of Meetings** ..		719 16 6				
	„ **International Astronautical Federation—**						
369	Contribution and Expenses of Congress		1104 6 1				
52	„ **Income Tax**		42 3 0				
	„ **Depreciation—**						
181	Furniture and Equipment ..	235 18 0					
58	Library	50 0 0					
			285 18 0				
250	„ **Transfer to Benevolent Fund** ..		500 0 0				
394	„ **Excess of Income over Expenditure**		886 0 5				
£11,530			£11,905 14 4	£11,530			£11,905 14 4

BALANCE SHEET as at 31 December, 1959

1958 £	Capital and Reserves	£ s. d.	£ s. d.	1958 £	Fixed Assets	£ s. d.	£ s. d.
	Accumulated Fund—				**Furniture and Equipment—**		
4177	Balance at 1 January, 1959..	4571 5 2		1444	At cost	1679 17 9	
394	*Add* Excess of Income over Expenditure	886 0 5		894	*Less* Depreciation to date ..	1129 17 9	
			5457 5 7				550 0 0
4571				550			
1888	**Compounded Subscriptions Reserve**		1913 13 6		**Library—**		
56	**Income Tax Reserve**		47 3 3	530	At cost	530 4 2	
				380	*Less* Depreciation to date ..	430 4 2	
6515	**Total of Capital and Reserves**		7418 2 4				100 0 0
				150			
	Current Liabilities				**Investments—**		
515	**Subscriptions Paid in Advance**	505 16 6		1000	3½% Defence Bonds (P.O. Issue)..	1000 0 0	
1541	**Sundry Creditors**	2608 8 7		2000	4% City of London Building Society Deposit Account ..	2000 0 0	
			3114 5 1				3000 0 0
				3700	Total of Fixed Assets ..		3650 0 0
					Current Assets		
					Sundry Debtors and Payments		
				88	**in Advance**	304 15 9	
					Cash at Bank—		
				2532	Deposit Account	4532 0 0	
				2244	Current Account	2025 15 10	
				7	**Cash in Hand**	19 15 10	
							6882 7 5
£8571			£10,532 7 5	£8571			£10,532 7 5

Certified to be a true copy

L. R. Shepherd } *Members of*
G. V. E. Thompson } *the Council*

L. J. Carter, *Secretary*

REPORT OF THE AUDITORS TO THE MEMBERS OF THE BRITISH INTERPLANETARY SOCIETY LTD.

We have obtained all the information and explanations which to the best of our knowledge and belief were necessary for the purposes of our audit. In our opinion proper books of account have been kept by the Society so far as appears from our examination of those books. We have examined the above Balance Sheet and annexed Income and Expenditure Account which are in agreement with the books of account. In our opinion and to the best of our information and according to the explanations given to us, the said accounts give the information required by the Companies Act, 1948, in the manner so required, and the Balance Sheet gives a true and fair view of the state of the Society's affairs as at 31 December, 1959, and the Income and Expenditure Account gives a true and fair view of the surplus of income over expenditure for the year ended on that date.

15, Craven Street, London, W.C.2.
28 *February*, 1960.

K. READHEAD & CO.,
Chartered Accountants

NEWS AND ANNOUNCEMENTS

B.I.S. NEWS

Lecture on Russian Space Research

Professor Alla Masevich, Vice-President of the Astronomical Council of the Academy of Sciences of the U.S.S.R., addressed a meeting of the Society in London on 10 February. The meeting was arranged at short notice when it was learnt that she was to visit this country for a few days for consultations with British scientists, and it was therefore not possible to announce it in the list of meetings or the Society's publications. However, as many members in the London area as possible were notified of the lecture and announcements were made to the technical press.

The meeting was held in the Hoare Memorial Hall at Church House, Westminster, and over 500 attended. Apologies must be made for the quality of the illustrations; this was partly due to the necessity to project some photographs through an epidiascope, and partly to the fact that the standard Russian slide is a few millimetres larger than the standard British slide-holder.

Professor Masevich described the instruments used and results obtained in Soviet space research, and outlined the organization of Moonwatch stations (in which she has played a leading part), but did not deal with the launching vehicles. She has an excellent command of English and dealt competently with the many questions which were asked at the end of the lecture.

Appointment of Full-Time Secretary

Council has decided that the finances of the Society are now such as to permit the appointment of a full-time Secretary, the need for this officer having been badly felt for some years past. With the growth in membership and activities of the Society the pressure on the Headquarters staff increases continuously. In addition to spending more time on the direction of the work of the staff, a full-time Secretary will be able to undertake the many duties necessary for the further development of the Society.

Mr. L. J. CARTER, who has been employed as Secretary on a part-time basis since 1945, has been appointed to the new post and will take up his duties on 1 July.

Commonwealth Spaceflight Symposium

The Proceedings of the Commonwealth Spaceflight Symposium, which was held in London last August, are now being printed and will be published by Academic Press Ltd.

Copies of the Proceedings may be purchased from the Interplanetary Publishing Company, 12, Bessborough Gardens, London, S.W.1.

Arrangements for holding the Second Commonwealth Spaceflight Symposium are already under consideration. An announcement concerning this will appear in the *Journal* as soon as a date and place for the meeting have been chosen. Meanwhile, the Council would welcome suggestions as to speakers, or offers of papers, particularly from oversea.

Professor Masevich receives a bouquet from the Secretary at the conclusion of her lecture. *At left:* Dr. W. R. Maxwell (*Vice-Chairman of Council*), who presided.

Election of Members

The following elections were made at the Council Meeting on 6 February, 1960.

New Fellows.

STANLEY ARMSTRONG, M.A., 52, Brook Road, Borehamwood, Hertfordshire.
DAVID EARLE BAILEY, M.A., Ph.D., 11, Cotswold Avenue, Hazel Grove, Stockport, Cheshire.
CEDRIC ARNOLD BELL, B.A., A.M.I.E.E., The Paddocks, Hurst, Twyford, Berkshire.
ROGER HENRI BETEILLE, Nysa, Ave. de la Mancha, La Napoule, Alpes-Maritimes, France.
BRUCE BURTON BOLLERMANN, M.S., 29, Walker Road, Lee Forest, Fairfax, Va., U.S.A.
JOHN DALZIEL BUCKNER, M.R.C.S., L.R.C.P., L.M.S.S.A., Taranaki Street, Picton, New Zealand.
GEOFFREY PATRICK COATES, D.L.C., Quinn's Hotel, 48, Sheen Road, Richmond, Surrey.
WILLIAM WARD TURNER CRANE, Ph.D., 700, Scarlett Drive, Towson 4, Md., U.S.A.
EDWARD MARK DOWLEN, A.F.R.Ae.S., D.C.L., D.C.Ae., Plough House, Codicote, Hertfordshire.
JAN GEERTSMA, Van Limburg Stirumstraat 12, Huizen (NH), Netherlands.
JAMES J. HARFORD, B.E., American Rocket Society, 500, Fifth Avenue, New York 36, N.Y., U.S.A.
MARTIN DOWNING HAZELL, B.Sc., D.I.C., 38, Beverley Way, London, S.W.20.
WELLINGTON H. T. LOH, Sc.D., 3701, Bellaire Circle, Fort Worth, 9, Texas, U.S.A.
LOUIS MARNAY, Villa Rouselou, Av. Roi Albert, Cannes, Alpes-Maritimes, France.
CLAYTON MCDOLE, M.S., Ph.D., Apt. 6, 20633, Van Owen Street, Canoga Park, Calif., U.S.A.
THOMAS KENNETH MCGARRY, B.S., 600E, Westmoreland Road, Falls Church, Va., U.S.A.
JOHN GEORGE MEITNER, Ph.D., 11070, Strathmore Drive, Apt. 28, Los Angeles, Calif., U.S.A.
SAMUEL MELVILLE, 8, Square de Clignancourt, Paris 18e, France.
MARCEL NICOLET, D.Sc., 30, Ave. Den Doorn, UCCLE, Brussels 18, Belgium.
MAX S. OLDHAM, M.S., Ph.D., ODDR & E (SW), 3E-119, Pentagon, Washington 25, D.C., U.S.A.
EDGAR AUGUSTINE O'NEIL, B.S., M.E., 71, Franklin Street, Englewood, New Jersey, U.S.A.
PATRICK CHRISTOPHER PARKS, M.A., G.R.Ae.S., Dept. of Aeronautics and Astronautics, The University, Southampton.
JEAN CHARLES PAROT, 5, rue de l'Université, Paris 7e, France.
PIERRE HENRI SATRE, 1, Boulevard de la République, Chatou, Seine-et-Oise, France.
EDWARD ARTHUR ALEXANDER SHACKLETON, O.B.E., M.A., BARON SHACKLETON OF BURLEY, 38, South Audley Street, London, W.1.
JOHN MICHAEL SHARPEY-SCHAFER, O.B.E., Hydrographic Dept., Admiralty, London, S.W.1.
JOHN ANTHONY TAYLOR, B.Sc., 61, Kenilworth Drive, Croxley Green, Rickmansworth, Hertfordshire.
BENJAMIN LOUIS TOLER, 502, Ridge Road, S.W., Vienna, Va., U.S.A.
JOHN P. VINTI, Sc.D., Section 11.4, National Bureau of Standards, Washington 25, D.C., U.S.A.
CECIL JACOB WADDINGTON, B.Sc., Ph.D., 3A, Napier Road, Redland, Bristol, 6.
FRANKLIN DONALD WITTMER, M.S., 710-168th S.E., Bellevue, Washington, U.S.A.

Members elected to the Fellowship.

NORMAN J. BOWMAN, A.B., M.S., Ph.D., 2023, Waverley Street, Philadelphia, Penn, U.S.A.
EMIL R. SHAW, B.Ind.Eng., Box 532, Senecaville, Ohio, U.S.A.

New Associate Fellowship.

NORMAN, L. BAKER, B.S., 1426, G Street, N.W., Washington 5, D.C., U.S.A.
ARTHUR LEIGHTON BRAKE, "Lavenders," Barton, nr. Winscombe, Somerset.
LEONARD JOHN BRISTOW, A.F.R.Ae.S., 69, Harcourt Street, Newark, Nottinghamshire.
ALAN CARLISLE CARR, 1, Geneva Terrace, Spotland, Rochdale, Lancashire.
KENNETH CHINNER, 74, Doverdale Road, Ettingshall Park Farm Estate, Wolverhampton, Staffordshire.
JOHN HENRY DAVIES, B.Sc., 7, Shop Row, Tredegar, Monmouthshire.
THOMAS ROY DUTTON, Flat 2, 295, Bramhall Lane, Davenport, Stockport, Cheshire.
MALCOLM FARNSWORTH, B.Sc., "Green Gables," Gate Lane, Freshwater Bay, Isle of Wight.
KLAUS BERNHARD LASCH, B.Sc., 7, Montrose Avenue, Wakefield, Mass., U.S.A.
JOHN STEWART LATHAM, B.Sc., R.A.A.F. Staff, Australia House, Strand, London, W.C.2.
JAMES MCKENZIE, 38, Albert Street North, Bangor, Co. Down, Northern Ireland.
DENIS JOHN MOTTRAM, A.R.Ae.S., 5, Limecroft Close, West Ewell, Surrey.
HUGH RONALD ALAN PRICE, Westerland Cottage, Westerland, Paignton, Devon.
CLAUDE FREDRICK SCOTT, B.Sc., 93, St. John's Hill, London, S.W.11.
ROBERT ALLAN THOMPSON, B.S., 1954, Seneca Drive, Euclid 17, Ohio, U.S.A.
CARL ALLAN WALTER WELLS, G.I.Prod.E., 162, Littleover Lane, Derby.
BRIAN JOHN SAMUEL WILKINS, B.Sc., 38, Norfolk Avenue, Southgate, London, N.13.
ROYCE OSBORNE WINDLEY, 7, Walsden Grove, Burnley, Lancashire.

Members elected to Associate Fellowship.

DAVID STANLEY FAGG, 76A Stafford Road, Kilburn, London, N.W.6.
ROBERT GILCHRIST, B.Sc., "Brookfield," Mottingham Lane, London, S.E.9.
PETER LEONARD STOKES, 42, Tintern Avenue, Kingsbury, London, N.W.9.
HARRY WHITFIELD, B.Sc., A.R.C.S., 5, Findon Hill, Sacriston, Durham.

Members elected to Senior Membership.

JOHN HERBERT DENNIS, 17, Gidlow Avenue, Wigan.
ARTHUR JOHN DOIG, 59, Sligo Terrace, Dunedin, N.W.1, New Zealand.
ERNEST DYSON, 302, Paramount Apartments, 2, Shan Kwong Road, Hong Kong.
CLIVE EDWARD GEORGE ERL, 13, Cedar Way, Sunbury, Middlesex.
GEOFFREY PETER GILBERT, 67, Hazelwood Avenue, Morden, Surrey.
WILLIAM DAVID HORTON, 40, Wellington Road, Wallasey, Cheshire.
FREDERICK GEORGE JONES, 89, Drewitt Crescent, Crossens, Southport, Lancashire.
GORDON EDWARD JONES, 2, Glyn-y-Coed Road, Victoria Gardens, Neath, Glamorgan.
KATHLEEN JONES, 262, Wilbraham Road, Manchester, 16.
WILLIAM MCCOMBIE, 42, Revoch Drive, Knightswood, Glasgow, W.3.
DONALD CHARLES MAYNE, 63, Goddard Road, Beckenham, Kent.
THOMAS HENRY O'DELL, 15, Norries Drive, Wallingford, Berkshire.
ALAN FRANK PETTIFER, 214, Rochester Road, Gravesend, Kent.
GORDON RENDLE PICKARD, Lorton Park Cottage, High Lorton, Cockermouth, Cumberland.
CECIL ROBINSON, 16, Eton Avenue, Plymouth, Devon.
GEORGE WILLIAM SCHOFIELD, 56C, Cecil Road, Walthamstow, London, E.17.
ALVIN LEON SMALL, c/o Mrs. R. W. McLendon, P.O. Box 307, Beaumont, Mississippi, U.S.A.
GEORGE HAROLD THOMAS, 42, Bown's Road, Kogarah, Sydney, N.S.W., Australia.
ALEXANDER GEORGE BRUCE THOMSON, 16, Victoria Place, Banff.
JOHN THOMAS TURNER, 51, East Street, Horncastle, Lincolnshire.
TERENCE PAUL VERNON, 81, Brookehowse Road, Bellingham, London, S.E.16.
WILLIAM PATRICK ADAMS, M.E., 891, North Ohio Street, Arlington 5, Va, U.S.A.
SUSAN VAUGHAN BILLINGSLEY, M.A., Ph.D., 707, East Adams Avenue, Orange, Calif., U.S.A.
STEPHEN BODDY, 57, Brook Road, Northfleet, Kent.
RENE ERIC BULL, "Ascona," 41, Forester Road, Thorneywood, Nottinghamshire.
BERNARD JOHN CARR, 50, Church Road, Alphington, Nr. Exeter, Devon.
AVERIL BURTON CHATFIELD, B.S., 5114, Newton Street, Torrance, Calif., U.S.A.
THOMAS FRANK CHEANEY, B.S., c/o Broward Title Co., P.O. Box 1382, Ft. Lauderdale, Florida, U.S.A.
MALCOLM COCKBURN CLAPPERTON, 125, Northumberland Road, North Harrow, Harrow, Middlesex.
ROY EDWARD CLOUGH, 125, "Handsworth," Coventry Road, Burtage, Hinckley, Leicestershire.
JOHN HOWARD COLEMAN, 226½, East 62nd Street, New York 21, N.Y., U.S.A.
JAMES ROBERT CONNER, 69, Shelvers Way, Tadworth, Surrey.
LUCIEN HARDING COY, 1027, Felbar Avenue, Torrance, Calif., U.S.A.
GEORGE VINCENT COYNE, A.B., Ph.D., Georgetown University, Washington 7, D.C., U.S.A.
JOHN ERIC DANIEL DAVIES, Heddfryn, Cefntiresgob, Llandeilo, Carmarthenshire, S. Wales.
ANTONY DEVEREUX, 36A, Blackacre Road, Theydon Bois, Essex.
ROBERT N. DEWITT, B.S., 3812, Gesman Place, Huntsville, Ala., U.S.A.
JOHN ALFRED ENSELL FARBROTHER, "Greenfields," Cramer Street, Stafford.
SAMUEL ROBERT FRIEDMAN, 3722, Appleton Street, N.W., Washington 16, D.C., U.S.A.
ANTHONY GIBBS, Spurfold House, Peaslake, Surrey.
GORDON GRAHAM, 58, Woolton Road, Wavertree, Liverpool, 15.
NEIL SPENCER HAILSTONE, 147, New Road, Booker, High Wycombe, Buckinghamshire.
JOE WILLIAM HALDEMAN, 5420, Burling Road, Bethesda 14, Maryland, U.S.A.
GEOFFREY ROWLAND HALL, 32, Cameron Avenue, Ottawa, Ontario, Canada.
RUTH FRANCES HEISEY, 10030, Falls Road, Potomac, Md. U.S.A.
ANN HUTCHINS, 57, Grenville Gardens, Woodford Green, Essex.
SIVELL WILLIAM LANE, c/o Gage, 226, Milton Road East, Edinburgh, 15.
RODNEY JAMES LANGAN, 207, Blackpool Old Road, Poulton le Fylde, Nr. Blackpool, Lancashire.
ALFRED JOHN LEDNER, 3, Church Street, St. Mary's, Sandwich, Kent.
ARTHUR GEORGE LIGHTFOOT, 11, Overdale Gardens, Langside, Glasgow, S.2.
ERNEST DOUGLAS MACKAY, Neatherlea, Lade Brays, St. Andrews, Fife.
RAY WILLIAMS MCKEE, 2107, Ninth Avenue, Greeley, Colorado, U.S.A.
ROBERT NICHOLAS MELLAMPHY, 74, Orford Street, Ipswich, Suffolk.
ALFRED JAMES MORENCY, M.S., Oxbow Road, Concord, Mass., U.S.A.
ATHELSTAN ARTHUR WILLIAMS MYLES, 267, Ivydale Road, Waverley Park, London, S.E.15.
PETER JAMES O'BEIRN, "Lorelei," Threadneedle Road, Salthill, Galway, Eire.
GEORGE O. OKIKIOLU, Baptist Boys' High School, Abeokuta, Nigeria.
JOHN CHRISTOPHER PEALE, B.S., M.A., 1254, South 8th Street, Hawthorne, Calif.
GEOFFREY WALLACE PLOWMAN, 58, Lincoln Road, Walsall.
STUART PETER ROBBINS, 21, Folkington Corner, Woodside Park, London, N.12.
PETER ROBERT SILVERMAN, 7, Redlands Road, Solihull, Warwickshire.
KENNETH EDWARD SINGER, 36, Woodlands Close, Hendon, London, N.W 11.
MICHAEL OWEN STORER, 15, Salisbury Road, Moseley, Birmingham, 13.
MICHAEL WILLIAM THOMPSON, 78, Vale Road, Seaford, Sussex.
JOHN RUSELL TIPPETTS, 255, Warwick Road, Olton, Solihull, Warwickshire.
MICHAEL AUSTIN WARLAND, 70, Lonsdale Drive, Enfield, Middlesex.
DOUGLAS ERIC WARRY, 85, Glenwood Drive, Romford, Essex.
IRVING WEIMAN, A.B., M.S., 2320, Brentford Road, San Marino, Calif., U.S.A.
LEONARD WILLIAM WELCH, 240, Rush Green Road, Romford, Essex.
COLIN RICHARD WOOD, Manor Cottage, Frogmore Lane, Long Crewdon, Buckinghamshire.
JOSEPH CARL ANTHONY WOYAK, 618, Union Street, Stevens Point, Wisconsin, U.S.A.
BENJAMIN ZAXMAN, M.S., 530, West 120th Street, Apt. 9, Los Angeles, 44, Calif. U.S.A.
CHARLES JEREMY ZINO, 64A, Redcliffe Gardens, London, S.W.10.

New Corporate Member.

SUD-AVIATION, 37, Blvd. de Montmorency, Paris 16eme, France.

The following elections were made at the Council Meeting on 12 March, 1960:

New Fellows.

GEORGE ROLAND ARTHUR, M.Eng., Ph.D., 9, Flagstone Place, Levittown, Pa., U.S.A.
MICHAEL JOHN BROAD, D.I.C., 65, Trinity Avenue, Bush Hill Park, Enfield, Middlesex.
HELEN LUEDTKE BROOKS, M.A., Ph.D., 2648, Talmadge Road, Toledo 6, Ohio, U.S.A.
RICHARD ROY BURLEY, B.S., 3180, Melody Lane, Parma 34, Ohio, U.S.A.
JOHN OWEN CAMPBELL, B.S., 1004, Selby Avenue, Los Angeles 24, Calif., U.S.A.

CHARLES BRANDON CROW, A.B., M.D., 109, Montevallo Lane, Birmingham 13, Alabama, U.S.A.
DAVID STANLEY DEAN, B.Sc., 18, Brudenell Drive, Stoke Mandeville, Aylesbury, Buckinghamshire.
CHRISTOPHER BIRON STEWART DAWSON, B.A., Willow End, Locks Lane, Birdham, Chichester, Sussex.
LAURENCE E. FOGARTY, Ph.D., Aero.Eng. Dept., University of Michigan, Ann Arbor, Michigan, U.S.A.
JOHN GRAHAM FORESTER, A.M.I.Mech.E., 9, Wade Drive, Mickleover, Derby.
LEON GOTTLIEB, 17, Laver Street, Kew, E.4, Melbourne, Victoria, Australia.
FOSDICK EMERSON HILL, M.Sc., 6047, De Lay Avenue, Glendora, Calif., U.S.A.
RALPH JORDINSON, M.S., D.I.C., 14, Station Close, Brookmans Park, Hatfield, Hertfordshire.
ALEXANDER KARTVELI, 5, Richard Lane, Huntington, Long Island, N.Y., U.S.A.
GERALD RICHARD LITTLE, M.S., 8, Winners Circle, Florissant, Missouri, U.S.A.
ALBERT FRANCIS LOPEZ, B.S., 502, East Foster Avenue, State College, Penn., U.S.A.
DUANE TORRANCE MCRUER, M.S., 5903, South Croft Avenue, Los Angeles 56, Calif., U.S.A.
ANTHONY JAMES MOORE, B.Sc., 167, Great Brays, Harlow, Essex.
JOHN DRYDEN MOVIUS, M.E., 12671, Singingwood Drive, Brittany Woods, Santa Ana, Calif., U.S.A.
JAMES R. RANDOLPH, B.S., M.E., The Fox Hole, Sanbornville, New Hampshire, U.S.A.
JOHN WARREN SENDERS, A.B., 97, Arthur Avenue S.E., Minneapolis 14, Minnesota, U.S.A.
ALEXANDER MAIR SMITH, M.A., Ph.D., 94, Belper Road, Derby.
HOWARD SURTEES, M.Sc., 25, Tower Road, Strawberry Hill, Twickenham.
JOHN GRAHAM WALKER, M.A., 5310, Willard Avenue, Chevy Chase 15, Md., U.S.A.
IVOR EDWARD WOODROFFE, A.M.I.Mech.E., A.F.R.Ae.S., 39, Church Lane, Darley Abbey, Derby.

Members elected to the Fellowship.

PERCY EDWARD ARGYLE, M.A., 1499, Balfour Street, Penticton, British Columbia, Canada.
JOHN BARRY CARESS, M.Sc., 154, Buckingham Road, Canons Park, Edgware, Middlesex.
JOHN KEVIN HIGGINS, B.Sc., Ph.D., 33, Upthorpe Drive, Wantage, Berkshire.
ALLEN J. MACKINNOR, General Delivery, Winston-Salem, North Carolina, U.S.A.
PETER CLARKE MILLRAY, B.Sc., G.I.Mech.E., 13, Podsmead Road, Woodhouse Park, Manchester, 22.
LEON FRANK MORGAN, B.S., 1361, Miette Way, Sunnyvale, Calif., U.S.A.
JUAN ODENNAL, D.Sc., Caracas, P.O. Box 2442, Venezuela.
CECIL ALFRED PARTRIDGE, 56, Woodside Avenue, Cinderford, Gloucestershire.
BASIL PETERS, B.A., 8, Regent Close, Cranford, Middlesex.
GEORGE SHAPIRO, M.A., 3507, Joann Drive, Baltimore 7, Md., U.S.A.
ALAN HERBERT WICKENS, B.Sc., D.L.C., 30, Arlington Crescent, Moor Lane, Wilmslow, Cheshire.

New Associate Fellows.

ROBERT HOWARD BRYAN, Lanchester Hall, College of Aeronautics, Cranfield Bletchley, Buckinghamshire.
JOHN MILES CHAPMAN, B.Sc., 14, Kingley Road, Cashes Green, Stroud, Gloucestershire.
PHILIP KENYON CHAPMAN, B.Sc., c/o Australia and New Zealand Bank Ltd., 71, Cornhill, London, E.C.3.
ALEXANDER JAMES DEASY, 6, Falmouth Road, Whitley Wood, Reading, Berkshire.
ROBERT DICKINSON, "Highclere," 27, Irwin Crescent, Strandtown, Belfast, 4, Northern Ireland.
GEORGE ALEXANDER GAMBLE, 14, Elm Grove, Urmston, Manchester.
WILLIAM FREDERICK HOLST, M.S., 219, Lincoln Street, Newton Highlands, 61, Mass., U.S.A.
SIMON MACNAB HUMPHREY, 12, York Gardens, Bristol, 8.
HAROLD DOUGLAS JUDKINS, 67 A.M.Q., R.A.F., Sevanton Morley, Dereham Norfolk.
DONALD NED LASCODY, B.S., 119, South Bundy Drive, Los Angeles 49, Calif., U.S.A.
RODDIE MAXWELL RODEN, B.Sc., 5, East Dale Road, Melton, North Ferriby, Yorkshire.
DAVID DUNCAN LESLIE RISK, B.Sc., "Windermere," 26, Silver Birches Estate, Frimley Road, Ashvale, Aldershot, Hampshire.
BRIAN THOMAS ROGERS, 1, West Avenue, Pinner, Middlesex.
DERYCK CAMERON STAPLETON, c/o Westminster Bank Ltd., Haymarket, London, S.W.1.
PATRICK KAY WARRICK, 118, Sixth Cross Road, Twickenham, Middlesex.
JOHN RUSHTON WHITE, A.R.I.C.S., 7, Greenacre Close, Hunts Cross, Woolton, Liverpool, Lancashire.
PAUL VERNON WILSON, 115, Beechmount Avenue, Hanwell, London, W.7.

Members elected to Associate Fellowship.

JOSEPH CHARLES FISHER, B.Sc., Rush Common House, Abingdon, Berkshire.
BERNARD GARNETT, 33, Monckton Road, Copnor, Portsmouth, Hampshire.
DAVID MICHAEL JACKSON, B.Sc., 98, St. Stephen's Road, Sheinton, Nottinghamshire.
WILLIAM ANTHONY MACCALLUM, 21, Traprain Terrace, Haddington, East Lothian, Scotland.
WILLIAM ROBB, 67, Abbots Road, Grangemouth, Stirlingshire, Scotland.

Members elected to Senior Membership.

RICHARD DAVID BATES, Officers' Mess, R.A.F., Bicester, Oxfordshire.
JOHN BERNARD BEVAN, 9, First Avenue, Maroubra, Sydney, New South Wales, Australia.
EDMUND BRUSKI, 850, Lois Avenue, Sunnyvale, Calif., U.S.A.
CORNELIUS STEPHEN FELLIN, 172-07, 35th Avenue, Flushing 58, New York, U.S.A.
PETER ALLAN LIEVAART, 56, Isis Street, Wahroonga, New South Wales, Australia.
LADY MARGARET VANE-TEMPEST STEWART, Londonderry House, 24, Hertford Street, London, W.1.
JACK LESLIE WINTERBOURNE, 89, Oaks Avenue, Worcester Park, Surrey.

New Members.

JOHN ALAN WILLIAM ARTHUR BALLS, 32, Green Lane, Eltham, London, S.E.9.
MICHAEL JAMES BOREHAM, The Lodge, "Holmwood," Kingston Hill, Surrey.
JEANETTE CHESTER, 59, Woodstock Road, Barnsley, Yorkshire.
THOMAS WILLIAM CONLON, 16, Warkworth Crescent, Westlea Estate, Seanan, Co. Durham.
ARNE ELTERVAAG, Vistegt. 17, Stavanger, Norway.
VASSILIJ ANDZEEVITCH FEDOROV, 16, Kensington Palace Gardens, London, W.8.
JOHN OSWIN CRANGLE, 18, Kent Terrace, Haswell, Durham.
DINSHAW RUSTOMJI HEERAMANECK, A.M.I.Plant E., 12, Alexandra Road, New Gamdevi, Bombay 7, India.
DAVID JOHN HIBBIN, Sunnyside, Cotterbury, Balckawton, Totnes, South Devon.
COLIN CHARLES PHILIP INGLETON, 130, Brackens Lane, Alvaston, Derby.
BYRON TERENCE JEEVES, 58, Sharrard Grove, Sheffield, 12.
ANAND KHOPKAR, 3, Harrington Square, London, N.W.1.
WILLIAM ALOYSIUS KINNEY, A.B., University Club, 1135, 16th Street, N.W., Washington 7, D.C., U.S.A.
GEIRR LEISTAD, Tunveien 11, Charlottenlund, Norway.
ALBERT LAURENCE LINTERN, Rush Common House, Abingdon, Berkshire.
MICHAEL FENWICK MATTINGLY, 4320, Fessenden Street, N.W., Washington 16, D.C., U.S.A.
EARL PHILIP MCQUATTERS, 796, 20th Street, San Bernardino, Calif., U.S.A.
NORMAN HECTOR MELROSE, 2, Highfield Avenue, Prestwick, Ayrshire, Scotland.
LAURENCE A. MOORE, Jnr., Box 4065, 7, Corners Station, Falls Church, Virginia, U.S.A.
ALAN MORRELL, 1, South Avenue, Burnage, Manchester, 19.
JIM NEW, Route 1, Lilbourn, Missouri, U.S.A.
MANUEL-JOSE NORMAN, 45, Buckleigh Road, Streatham Common, London, S.W.16
EMMA LOUISE PARKS, 9, Clarendon Lodge, 56, Clarendon Road, Holland Park, London, W.11.
PER RAVNSBORG-GJERTSEN, Institut National des Sciences Appliquées, 20, Avenue Albert-Einstein, Villeurbanne, Rhône, France.
JOSEPH BAILEY SERRETT, M.S., 10131-16, Buford Avenue, Inglewood 2, Calif., U.S.A.
PAUL MAURICE SMITH, "Ardenhoe," Burton Green, Kenilworth, Warwickshire.
ROBERT JOHN SYME, 28, Mardale Crescent, Edinburgh, 10.
BRIAN JAMES TABNER, 26, Pinfold Lane, Penn, Wolverhampton, Staffordshire.
LEONARD CHARLES FREDERICK WALDOCK, 34, Hillcrest, Roe Green, Hatfield, Hertfordshire.
WILLIAM HALL WATSON, Merton Hotel, 6, Mackerston Place, Largs, Ayrshire.
ROY WHITWORTH, 56, Sunny Bank Road, Sutton Coldfield, Warwickshire.

The following elections were made at the Council Meeting on 9 April, 1960:

Fellows.

WALTER K. DOYLE, M.S., 2920, St. Paul Street, Baltimore 18, Md., U.S.A.
HANS KARL KARRENBERG, M.S., 1866, Knoxville Avenue, Long Beach, 15, Calif., U.S.A.
TREVOR DAVID LEWIS, Engr.-in-Chief, Ghana Govt., P.O. Box 136, Accra, Ghana.
VICTOR FREDERICK MORLEY, Trials Establishment (Guided Weapons), Royal Artillery, Ty Croes, Anglesey, Wales.
JOSE MANUEL PANIAGUA-BAQUERO, 98-05, 63rd Road, Rego Park 74, New York, U.S.A.
EUGENE HENRY PRIMOFF, B.A., 82-86, Parsons Boulevard, Jamaica 32, New York, U.S.A.
DONALD E. WEBB, B.A., 5737, Mayville Drive, Dayton, 32, Ohio, U.S.A.

Members elected to the Fellowship.

IVER IGELSRUD, B.S., Ph.D., 563, White Oak Place, Worthington, Ohio, U.S.A.
OSCAR LLOYD KING, A.B., 833, Lincoln, Apt. No. 8, Santa Monica, Calif., U.S.A.
WILLIAM JOHN ROBINSON, B.Sc., Ph.D., 64, Malford Court, Woodford Road, Woodford, London, E.18.

New Associate Fellows.

GERALD BUGO, 8, Homefield Close, Swanley, Kent.
ARTHUR JAMES CHALK, 18, Prout Grove, Neasden, London, N.W.10.
ERNESTO B. JACIR-SALAME, Apartado de Correos 6744, Caracas, Venezuela, South America.
JOHN MERCY, L.D.S. (R.C.S.), Eland House, The Avenue, Ickenham, Uxbridge, Middlesex.
RONALD WILKS, Apt. 2, 3498, Blair Circle, Atlanta 19, Georgia, U.S.A.

Members elected to Associate Fellowship.

AIDAN ERIC BUTCHER, "Lynton," Durfolk Hill, Warnham, Horsham, Sussex.
ANTHONY EDWARD FANNING, M.B.E., D.S.C., F.R.A.S., 116, Ducks Hill Road, Northwood, Middlesex.
JOHN WALTER LESTER WARREN, 5, St. Mary's Road, Shirehampton, Bristol.

Members elected to Senior Membership.

ROY FREDERICH CHARLES ELMER, 50, Buckland Crescent, Windsor, Berkshire.
DAVID ALLAN GREENFIELD, "Lynwood," 185, Thundersley Park Road, South Benfleet, Essex.
PETER GRIFFITHS, 133, Colindale Avenue, Colindale, London, N.W.9.
WILLIAM HOGO HENDERSON, 220, Hugh Street, Kinross, Scotland.

New Members.

SIDNEY CHARLES BOWEN, 35, Crosshill Avenue, Campbeltown, Argyllshire.
WILLIAM PRIESTLEY BUTTERFIELD, "Mytholme," Harden, Bingley, Yorkshire.
HANS KRISTIAN ECKHOFF, Vaalandsgt 68, Stavanger, Norway.
ROBERT T.EDGAR, 557, Terrill Avenue, Los Angeles 42, Calif., U.S.A.
KEVIN JOSEPH FLEMING, 142, Alnwick Road, Intake, Sheffield, 12.
EURICO SIDONIO GOUVEIA XAVIER LOPES FONSECA, Palacio da Independencia, Lisbon, Portugal.
BRIAN EDWARD GILL, 13, Manor Road, London Colney, Hertfordshire.
BARRY LAWSON, 5, The Poplars, South Hylton, Sunderland, Co. Durham.

RONALD CHESTER MILLER, 17, Johnstone Terrace, Twechar, Dumbartonshire, Scotland.
MICHAEL LESLIE NORMAN, 99, Megalong Street, Leura, New South Wales, Australia.
GEORGE MANFRED ROENSPIESS, 47, Merner Avenue, Kitchener, Ontario, Canada.
ALBERT JOHN VAN CLEAVE, P.O. Box 1066, Taos, New Mexico, U.S.A.
ARTHUR HAROLD WELLS, 11, High Beeches, Chelsfield, Kent.
GEOFFREY WHITEHEAD, 26, Barwick Road, Crossgates, Leeds, 15.
DAVID TRENWITH WHITTINGHAM, R.R.A.F. Box 8431, Causeway, Salisbury, Southern Rhodesia.

OBITUARY

Hugh Percival Wilkins: 1896–1960

By the death of H.P. Wilkins, on 1960 January 23, Britain loses her most distinguished student of the Moon. He had been ill for some weeks, following a heart attack, but had been making such good progress that a full recovery had been expected.

In view of Wilkins' standing and reputation, he was widely believed to be a professional astronomer. Yet such was not the case; he remained an amateur throughout his life, though he had many contacts among professional scientists all over the world. From his private observatory in Bexleyheath he made useful observations of the planets from time to time, but these were merely incidental to his main work—the study of the lunar surface.

Wilkins was born and educated in Carmarthen, in South Wales; though he lived in England for much of his later life, he never lost his strong Welsh accent. He served in the Army during the 1914–18 war, and upon demobilization became an engineer. Following his marriage he moved to Kent, and in 1941 finally gave up practical engineering to join the Ministry of Supply. He retired from this post at the end of 1959 with the intention of devoting his full time to astronomy, and it is tragic that he was unable to carry out his wish.

His interest in astronomy dated back to his schooldays, and he began by making telescopes out of small lenses and cardboard tubes. His lunar observation book dates back to 1909, and even at that early age his skill was evident. After the war he started to grind mirrors, and became very proficient; for many years he used a 12½-in. reflector of his own construction, though he later replaced it with a fine 15½-in. which he acquired elsewhere.

Wilkins deliberately set out to draw a map of the Moon which would be accurate, and yet far more detailed than any previously constructed. By 1924 he had completed and published a map 60 in. in diameter, but this did not satisfy him, and he at once commenced a second map to a scale of 300 in. to the Moon's diameter. It took him twenty years, and involved thousands of drawings and countless hours at the telescope, together with measurements and studies of photographs. As soon as this vast map was complete, he began to revise it, and the second edition appeared in 1954. To make it as detailed as possible, Wilkins carried out observations not only with his own telescope, but with giant instruments in Europe and America. Even then he was not satisfied; having finished his second map, and written a comprehensive text giving a description of every named formation on the Moon, he began yet another revision, though unhappily he did not live to complete it.

In 1946 Wilkins was asked to assume the Directorship of the Lunar Section of the British Astronomical Association, which was then largely dormant. He accepted the challenge, and tackled the situation with such energy and enthusiasm that he transformed the Section into a useful and extremely active body. When he resigned, in 1956, his successor (E. A. Whitaker) inherited an organization in full working order, and including over a hundred members. Subsequently Wilkins formed the International Lunar Society, becoming its first President.

Wilkins was fifty years old by the time the Second World War ended, and his health was never particularly good, but he had the enthusiasm and modern outlook of a young man. He was essentially progressive, and became an active member of the British Interplanetary Society, contributing to its publications, lecturing at its meetings, and serving on its Council for some years. He never had the slightest doubt as to the future of space research, and he had the courage of his convictions; he joined the Society at a time when some professional scientists still regarded space exploration as "not quite respectable," but Wilkins was much too far-sighted to be disturbed.

He was an excellent lecturer, and broadcast frequently on both sound radio and television; moreover he wrote several astronomical books in addition to his exhaustive volume about the Moon. In recognition of his work, the University of Barcelona conferred upon him the honorary degree of Ph.D., and he was invited to serve upon the relevant commission of the International Astronomical Union—an honour seldom afforded to an amateur, however eminent. His interests were wide; among them was geology, and he descended the crater of Vesuvius to take some magnificent colour pictures. He continued all these activities until a few weeks before his death.

One of Wilkins' greatest virtues was his readiness to help others. He was always prepared to give assistance and advice, and there are many who owe him a debt of gratitude; he was particularly interested in helping young enthusiasts, and the visitors to his observatory in Bexleyheath were numbered in hundreds. Those who came to him for assistance were never disappointed.

Like all those who achieve a wide reputation, Wilkins had his critics, and was the victim of several unpleasant attacks in print. These attacks he did not understand, and was not interested in understanding; he was unfailingly courteous himself, and had no common ground with those who were not.

His marriage was ideally happy; he is survived by his widow and their daughter. Wilkins' death is a great loss to astronomical science, and is keenly felt by his many friends throughout the world.

PATRICK MOORE.

JOINT ACTIVITIES

European Spaceflight Symposium

The first European Spaceflight Symposium is to be held in London early in 1961. It will be organized by the Society, with the co-operation of the other principal European astronautical societies. A proposal to hold such a meeting was first voiced in 1959 and Council has been giving consideration to the matter ever since the London Congress of the International Astronautical Federation.

The date has been chosen to avoid a clash with future I.A.F. Congresses. That in 1961 is scheduled to take place in the United States. Desirable and welcome though this is, because of the great achievements of the U.S.A. in the field of astronautics, it is evident that many Europeans will find the meeting much less convenient to attend than the previous Congresses, which have all taken place this side of the Atlantic.

The proposed Symposium will fill the gap left by the temporary departure of the I.A.F. over the ocean, but is to be held some months before the provisional date of the I.A.F. Congress so that attendance at both functions will be possible.

There is another reason why the Symposium should arouse considerable interest. Its theme is to be the possibility of setting-up a co-operative European Spaceflight Programme.

Further announcements concerning the Symposium will be appearing in the *Journal*, but the Secretary would be glad to hear from any who might contemplate attending or presenting a paper at the technical sessions.

Eleventh International Astronautical Congress

The Eleventh International Astronautical Congress will be held in Stockholm during the week 15–20 August, 1960, and is being organized by Svenska Interplanetariska Sällskapet (the Swedish Interplanetary Society). The address of the Secretariat is I.A.F.-60, Box 5045, Stockholm 5, Sweden (Telegrams: Astrocongress, Stockholm, Sweden; Telephone 10 32 48).

A preliminary notice concerning the Congress appeared on pp. 148–149 of the October *Journal*; details of the programme are now available and are given below.

The lectures and symposia will be held at the Royal Institute of Technology (Kungl. Tekniska Högskolan). The Space Law Colloquium will be at the Apollonia Theatre.

Participation is open to all and the fee for active participants will be Sw.Cr. 120 (approximately £8); this will cover attendance at the reception, opening ceremony and lectures, and the provision of the printed proceedings. Ladies and others accompanying active participants will be charged a fee of Sw.Cr. 40 (approximately £2 15s.); this will cover attendance at the reception, opening ceremony and lectures, participation in a special ladies' programme, but not provision of the printed proceedings.

Tickets for the banquet to be held on 19 August cost Sw.Cr. 45 each (approximately £3 2s.) each. The additional charges for the Drottningholm Theatre and Archipelago Excursions are approximately Sw.Cr. 35 (£2 10s.) each.

Payments may be made by remittance to Skandinaviska Banken, Stockholm, cheque account 127106, XIth International Astronautical Congress. A limited supply of registration forms for the Congress are available from the Secretary, B.I.S., 12, Bessborough Gardens, London, S.W.1, but oversea members will find it easiest to write direct to the Congress Secretariat at Stockholm.

The official agency responsible for providing hotel accommodation is Travel Bureau RESO, Postfack, Stockholm 1, who are also responsible for organizing tours in connection with the Congress. A reduction of 25% on all railway fares in Sweden can be obtained by all Congress participants on obtaining a voucher from RESO.

Flights to Stockholm from London are operated by British European Airways and Scandinavian Airlines System. The Night Tourist fare for the return trip is £37 6s. (for daylight flights, the fares are £58 7s. tourist, or £75 first class). Either Comet 4 or Caravelle aircraft are employed.

PROVISIONAL CONGRESS PROGRAMME

Sunday, 14 August

All day	Registration, at the Congress Bureau.
Evening	Informal reception for all participants at the Strand Hotel.

Monday, 15 August

Forenoon	Registration.
Afternoon	Opening of the Congress at the China Theatre. Reception at the City Hall by invitation of the City of Stockholm. Reception at the Technical and Science Museum.

Tuesday, 16 August

All day	Main Congress Lecture Sessions. Space Law Colloquium. Space Medical Symposium, Part 1 Small Sounding Rocket Symposium, Part 1.

Wednesday, 17 August

All day	Main Congress Lecture Sessions. Space Medical Symposium, Part 2. Small Sounding Rocket Symposium, Part 2.
Evening	A boat trip to the eighteenth-century Drottningholm Theatre, where a performance will be given. Return by bus.

Thursday, 18 August

All day	Open day. An excursion by boat through the Archipelago, with a luncheon at the Saltsjöbaden. Possibilities for open sea swimming.

Friday, 19 August

All day	Main Congress Lecture Sessions. Astrodynamics Symposium.
Evening	The Congress Banquet at the Winter Garden of the Grand Hotel Royal.

Saturday, 20 August

Forenoon	Main Congress Lecture Sessions. Possible Special Sessions.

Symposium on Rocket and Satellite Instrumentation

As announced in the February issue of the *Journal*, a one-day symposium on rocket and satellite instrumentation is being organized jointly by the British Interplanetary Society and the Society of Instrument Technology. Emphasis is being placed on work actually being undertaken, or projected within the United Kingdom during 1960.

The Symposium is to take place at Manson House, 26 Portland Place, London, W.1, on Thursday, **1 September, 1960**. Preprints of the principal papers will be provided to all symposium participants, who will be charged a Conference Fee of two guineas (£2 2s. 0d.); this will also cover the provision of light refreshments during the morning and afternoon sessions. *Bona fide* students will be admitted for a reduced fee of £1; librarians and others who do not wish to attend the meetings may obtain sets of preprints on payment of a fee of £1.

Registration forms and further particulars are obtainable from The Secretary, British Interplanetary Society, 12 Bessborough Gardens, London, S.W.1.

Symposium on Space Navigation

A one-day symposium on Space Navigation is being organized jointly by the British Interplanetary Society and the Institute of Navigation. It will comprise about six papers related to a particular mission: the early manned exploration of the Moon. Papers have already been promised from Professor Samuel Herrick (University of California, and Aeronutronic, a division of Ford Motor Co.), Maxwell Noton (California Institute of Technology) and D. J. Cashmore (English Electric Co.).

The symposium will be held in the Lecture Theatre of the Royal Geographical Society, 1 Kensington Gore, London, S.W.7, on Friday, **18 November, 1960**. Further announcements concerning the papers to be presented, conference fees, etc., will appear in the Journal. Members and others who are likely to attend should inform the Secretary as soon as possible.

ASTRONAUTICAL ABSTRACTS

Edited by J. HUMPHRIES and J. FOLEY

1959–60 PARTS 8/9

A list of abbreviations of titles of journals was included with the 1954 index and addenda have been published in subsequent issues of the *Journal*. A further addendum is given below:

Acta Tech. Acad. Sci. Hung.	Acta Technica Academiae Scientiarium Hungaricae.
Aero Medical Ass.	Aero Medical Association.
Aerospace Med.	Aerospace Medicine (*formerly* Journal of Aviation Medicine).
Amer. Inst. Biol. Sci. Bull.	American Institute of Biological Sciences Bulletin.
Amer. Soc. Naval Engrs. J.	American Society of Naval Engineers Journal.
Exper. Tech. Phys.	Experimentelle Technik der Physik.
Missile Design Devel.	Missile Design and Development.
Studii Cerc. Astron. Seism.	Studii şi Cercetări de şi Seismologie.
Texas State J. Med.	Texas State Journal of Medicine.

1—ASTRONOMY

.1 *General*

(1894) **Spatiography: geography for space**. H. Strughold. *Missiles and Rockets*, **3** (6), 106, 108 (*May*, 1958).

(1895) **Space astronomy**. K. R. Stehling. *Interavia*, **14**, 536–8 (*May*, 1959). Balloon- or rocket-borne astronomical instruments have given some improvement in quality and range of observation. Satellite observatories will be better but the ultimate must be a Moon-based station.

(1896) **Rocket astronomy**. H. Friedman. *Sci. Amer.*, **200** (6), 52–9 (*June*, 1959). Describes the advantages of rocket-borne telescopes and spectrometers, the results of observations in the ultra-violet, and solar spectral measurements into the X-ray region.

.5 *Planets*

(1897) **The planet Venus**. P. A. Moore. 132 pp., $3.00, *Macmillan, N.Y.* 15s., *Faber, London*. $2.60, *British Book Service, Toronto*. Book.

(1898) **The planet Jupiter**. B. M. Peek. 283 pp., 42s., *Faber, London* (1958). $8.50, *Macmillan, N.Y.* (1958). Book.

(1899) **Air on Mars? Yes—but . . .** *Missiles and Rockets*, **3** (6), 111 (*May*, 1958).

(1900) **The physical nature of the planets and their probable course of evolution**. J. F. Heard. *Canad. Aero. J.*, **5** (5), 184–6 (*May*, 1959). An account of the development of the present surface conditions of the planets. Mars and Venus are discussed in detail.

.7 *Moon*

(1901) **Introduction to the Moon**. D. Alter. 108 pp., $1.65, *Griffith Observatory, Los Angeles* (1958). Book.

(1902) **Moon's supply of atmosphere and water**. C. A. Ritchie. *Amer. Soc. Naval Engrs. J.*, **70**, 435–7 (*Aug.*, 1958).

2—PHYSICS

.1 *General*

[*See also* abstract no. 2024]

(1903) **On the use of the artificial Earth satellite to prove the general theory of relativity**. V. L. Ginzburg. *Exper. Tech. Phys.*, **5**, 89–92 (1957). (*In German.*)

(1904) **Twin paradox in special relativity**. R. H. Romer. *Amer. J. Phys.*, **27** (3), 131–5 (*March*, 1959). The familiar "travelling twin paradox" is discussed in a particularly simple manner, using special relativity only. The assymetrical ageing of the twins is predicted using only the relativistic definition of simultaneity and relativistic time dilatation. Possible objections to such a treatment are discussed.

(1905) **The time paradox and space vehicles whose speed reaches that of light**. *Umschau*, **5**, 132–4 (1 *March*, 1959). (*In German.*)

(1906) **Time dilatation in space travel**. K. R. Stehling. *Space Aeronautics*, **31** (5), 43–5 (*May*, 1959). Review of problems raised by time dilatation effects on interstellar flight. Arguments for and against its existence are discussed.

.5 *Heat and Thermodynamics*

(1907) **An optical method for the instantaneous measurement of the temperature of flames**. A. Moutet, C. Veret and L. Nadaud. *Rech. Aéronaut.*, **68**, 9–19 (*Jan.*, 1959). (*In French.*) Describes a method based on the spectroscopic line reversal technique of Kurlbaum and Fery, with developments which allow very rapid observations to be made. Applications to the measurement of rocket combustion temperatures, even during unstable burning, are described. (15 *refs.*)

.7 *Cosmic Radiation*

(1908) **Radiation belts around the Earth**. J. A. Van Allen. *Scientific American*, **200** (3), 39–47 (*March*, 1959). Satellites and lunar probe rockets indicate the presence of two zones of high-energy particles against which space travellers will have to be shielded.

(1909) **Pioneer IV data alters Van Allen theory**. *Aviation Wk.*, **70** (19), 31 (11 *May*, 1959). Radiation data from the U.S. solar satellite discussed. The two belts of radiation surrounding the earth are different in character and the outer one variable in accordance with solar activity. Measurements made out to 400,000 miles.

.8 *Other Upper Atmosphere Phenomena*

(1910) **The upper atmosphere**. H. S. W. Massey and R. L. F. Boyd. *Philosophical Library, N.Y.*, 333 pp., $17.50 (1959). Book.

4—BIOLOGY AND MEDICINE

.1 *General*

(1911) **The challenge of space biology**. W. O. Fenn. *Amer. Inst. Biol. Sci. Bull.*, **8** (2), 15 (1958).

(1912) **Medical sciences and space travel**. W. A. Kinney. 150 pp., $3.95. *Franklin Watts, New York, U.S.A.* (1959). Book.

(1913) **Life on other worlds**. H. S. Jones. *New Scientist*, **5** (112), 65–7 (8 *Jan.*, 1959). Conditions essential to well-developed forms of life are absent on the Moon, Jupiter, Saturn, Uranus, Neptune and Venus. There is a possibility that extremely primitive types exist on Mars.

(1914) **Bibliographic control of aviation and space medical literature**. A. J. Jacobius. *Prepr.*, 1959 *Meeting, Aero Medical Ass.*, (*April*, 1959). Discusses scope, purpose and organization of aviation and space medicine bibliographies with special reference to one in progress at the Library of Congress. Analyses distribution of aviation medicine literature.

(1915) **Exotic atmospheres on Earth**. H. Strughold. *J. Aviation Med.*, **30**, 311–4 (*May*, 1959). Simulation of various atmospheres.

.4 *Anatomy and Physiology*

[*See also* abstract no. 2027]

(1916) **Respiratory conditions in intercontinental rockets**. M.-V. Strumza. *Fusées*, **2**, 241–3 (*July*, 1957). (*In French.*)

(1917) **Study of animals during flights in rockets in the upper layers of the atmosphere**. Pokrowski. *Fusées*, **3**, 5–7 (*April*, 1958) (*In French.*)

(1918) **Human engineering of the sealed space cabin**. J. E. Ward and G. R. Steinkamp. *Texas State J. Med.*, **54**, 356–7 (*June*, 1958).

(1919) **History of research in space biology and biodynamics at the Air Force Missile Development Center, 1946–1958**. 114 pp., gratis, *Holloman Air Force Base, New Mexico, U.S.* (1959). Book.

(1920) **Man in space—factors in survival**. E. G. Aiken and E. B. Konecci. *Soc. Automot. Engnrs. J.*, **67** (1), 62–4 (*Jan.*, 1959). Discussion of problems of oxygen supply, weightlessness, ambient temperature and pressure.

(1921) **Reports on space medicine**. Gratis. *Randolph Air Force Base, Texas, U.S.* (*Feb.*, 1959). Book.

(1922) **State of the art: human factors**. *Space-Aeronautics*, **31** (3), 98, 100, 104, 106–8 (*March*, 1959). Problems discussed are those of radiation hazards and screening, the effects of acceleration and prolonged zero-*g*, and the provision of suitable cabin conditions.

(1923) **Wanted: spaceman**. *Interavia*, **14**, 292–3 (*March*, 1959), Describes the Mercury space capsule project and the requirements for its occupant.

(1924) **Space flight hazards caused by weightlessness**. H. J. von Beckh. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Lack of neuromuscular co-ordination and optical illusions are discussed. More difficulties may arise from alternation of high *g*-loads and weightlessness.

(1925) **Research on human performance during zero gravity**. E. L. Brown. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Zero gravity achieved for 12–15 sec. in cabin in C–131 B. Simple motor tasks accomplished and experience in free-floating conditions reported.

(1926) **Problems in space feeding**. H. C. Dyme. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Stresses in space studied for effect on nutritional requirements. Pre-cooked dehydrated foods with special reconstituting properties under development. Appropriate space feeding systems formulated.

(1927) **A device for simulation of reaction control problems in orbital maneuvers**. J. G. Gaume. *Prepr.*, 1959 *Meeting, Aero Medical Ass.*, (*April*, 1959). Development of air-supported simulator with three degrees of freedom.

(1928) **Work proficiency in a hermetically-sealed cabin**. S. J. Gerathewohl. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Results of seven-day confinement of D. G. Farrell. Tests showed maintenance of overall ability to learn but progressive irritability resulting in increased errors.

(1929) **Prolonged exposures in Navy full pressure suit at space equivalent altitudes**. A. L. Hall and R. J. Martin. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Total exposure time of subject in Navy Mk. III, Mod. 2 lightweight full pressure suit at over 80,000 ft. equivalent was 47 hr. out of total of 72 hr. at 35,000–140,000 ft. Results of physiological tests given; these show moderate stress condition.

(1930) **Performance and habitability aspects of extended confinement**. T. D. Hanna. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Results of tests on six men, isolated and confined in a small chamber for seven days breathing a relatively high oxygen concentration. All men worked for 10 hours a day and intellectual and psychomotor performance did not deteriorate.

(1931) **Heat load and CO_2 during simulated space flight**. W. R. Hawkins, G. T. Hauty and G. R. Steinkamp. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Subject underwent three simulated space flights of 48 hr. each and 30 days apart. Total cabin pressure 380 mm. Hg, oxygen 150 mm. Hg. Only changes were CO_2 concentration, diet and temperature—result presented.

(1932) **The potential application of hibernation in space travel**. R. J. Hock. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Problem is to lower body temperature to about −50° F. without ventricular fibrillation occurring, to maintain these conditions for long periods and to achieve positive arousal. Suggests that better understanding of natural hibernation will help.

(1933) **Engineering of the sealed cabin atmosphere control system**. S. L. Jacobson. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Discusses control of carbon dioxide, temperature, and humidity as well as supply of oxygen and ventilation. Deals with optimization of systems.

(1934) **The importance of the utricle in orientation**. W. H. Johnson. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). The vestibular nerve concerned with the utricle was cut in a number of animals leaving the semi-circular canals functioning. The results of subjecting these animals to zero-*g* are presented.

(1935) **Calculations of the radiobiological risk factors involved in future nuclear powered space vehicles**. E. B. Konecci and R. Trapp. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Surveys hazards including cosmic rays, X-rays and radiation bands around Earth and discusses shielding.

(1936) **Design and operation of photosynthetic gas exchanges for closed ecological systems**. W. A. Kratz and J. D. Fulton. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Long-range studies have been made and a recycling system has been built which has enabled small animals to stay alive over an extended period.

(1937) **Projecting man's brain into space.** A. M. Mayo. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Control of remote devices can be made more effective by allowing the human operator to mentally place himself in the vehicle he is controlling.

(1938) **Radiation dosage in flight through the radiation belt**. H. J. Schaefer. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Considers shielding for various types of radiation. Concludes that it seems inevitable to exceed the official permissible emergency dose of 25 rem. by a large margin.

(1939) **Airborne EEG recording as a means of studying and selecting pilots and crews in high-performance aircraft and space vehicles**. C. W. Sem-Jacobsen. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Tests on jet pilots in simulated combat flight give data about pilots' actual physiological capabilities under physical and mental stress. By telemetering EEG data pilots' alertness and level of consciousness may be followed.

(1940) **Potable water recycled from urine**. J. Sendroy and H. A. Collison. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Laboratory process has been developed which gives a 70% yield of water which is colourless and indistinguishable by taste and smell from distilled water. Rats supplied with this water showed no ill effects over a period of more than 30 days.

(1941) **Bio-logistics of space travel**. A. A. Taylor. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). For flight times

of several months recycling of air and water will be needed. For longer periods, in-flight production of food will also be necessary. Concepts for development and test of such systems are presented.

(1942) **An experimental model for the measurement of man's ecology in space.** P. R. Tobias. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Proposal to use computer to compare in-flight data on crew with basic mathematical model in order to determine significant changes in physio-psychologic parameters.

(1943) **NASA selects Project Mercury trainees.** *Aviation Wk.*, **70** (15), 35 (13 *April*, 1959). Names of seven volunteers selected for training for a manned satellite.

(1944) **Physiologic responses to stressful stratosphere flights.** N. L. Barr, B. E. Shepp, M. Yarczower and F. G. Standaert. *J. Aviation Med.*, **30**, 334–43 (*May*, 1959). Results suggest that high altitude balloon flights produced no physiologic reactions which could be measured by presently available techniques. (7 *refs.*)

(1945) **The duration of tolerance to positive acceleration.** H. Miller, M. B. Riley, S. Bondurant and E. P. Hiatt. *J. Aviation Med.*,**30**, 360–6 (*May*, 1959). Human tolerance to positive acceleration up to 6 *g* with and without anti-*g* suits. All subjects withstood 3 *g* for 1 hr. with no ill effects. Three out of eight subjects withstood 5 *g* for 4 min. without blackout.

(1946) **Reactions of a balloon crew in a controlled environment.** M. D. Ross. *J. Aviation Med.*, **30**, 326–33 (*May*, 1959). Reviews two-man gondola tests, both simulated and free flight undertaken by U.S. Navy. Warns that ground tests can be very misleading. Pressure suits considered to be unsatisfactory for long flight periods. (19 *refs.*)

(1947) **The "Manhigh" sealed cabin atmosphere.** D. G. Simons. *J. Aviation Med.*, **30**, 314–25 (*May*, 1959). Discusses cabin design, in particular choice of atmosphere. Total cabin pressure was 300 mm. Hg with 60% oxygen, 20% helium and 20% nitrogen. Results analysed. (10 *refs.*)

(1948) **Closed respiration-ventilation system for use with high altitude full pressure garment.** R. G. Willis and S. C. White. *J. Aviation Med.*, **30**, 344–50 (*May*, 1959). Describes development of laboratory-type equipment for operation over 12-hr. period. This has still to be reduced to a lightweight package suitable for use with a pressure suit.

(1949) **Measuring whole-body radiation determines effect on X-15 pilots.** *Aviation Wk.*, **70** (19), 69 (11 *May*, 1959). Report of meeting of Aerospace Medical Association at Los Angeles. Papers concerned with the detection of the effects of cosmic ray exposure on men, the effect of stress and fatigue under spaceflight conditions, and the problems of oxygen supply and bodily function at low pressures (*see also* abstracts nos. 1914, 1924–42, 1956).

(1950) **Human reactions during flight to acceleration preceded by or followed by weightlessness.** H. J. von Beckh. *Aerospace Med.*, **30**, 391–409 (*June*, 1959). Tests show that alternation of weightlessness and acceleration results in decrease of acceleration tolerance and of the efficiency of physiologic recovery mechanisms. (24 *refs.*)

(1951) **Implications of space radiations in manned space flights.** W. H. Langham. *Aerospace Med.*, **30**, 410–7 (*June*, 1959). Normal maximum allowable industrial levels are unrealistically conservative for application to spaceflight. More data on the nature of the van Allen belts are required. (25 *refs.*)

(1952) **NASA spells out space biology program.** J. A. Fusca. *Aviation Wk.*, **70** (22), 26–8 (1 *June*, 1959). Describes plans for the Mercury manned space capsule, and work beginning on associated problems.

(1953) **Heat protection for space crews.** E. T. Carter. *Space-Aeronautics*, **32** (1), 61–2, 64, 68, 70, 72 (*July*, 1959). An analysis of the many factors that influence man's response to heat. (7 *refs.*)

(1954) **Instrumentation for research on human performance.** D. B. Hatmaker. *Elect. Engng., N.Y.*, **78** (11), 1079–1084 (*Nov.*, 1959). Performance tasks for spacecraft operators and equipment for generating, displaying, monitoring, scoring and recording the tasks developed at the Human Factors Laboratory of Lockheed Aircraft Corp. Tasks include compensatory tracking, auditory vigilance, warning lights monitoring, arithmetic computation, pattern discrimination, probability monitoring and scale position monitoring. Also psychophysiological and supplementary instrumentation.

(1955) **Will *tilapia* be space travellers food?** M. Lorant. *Food Manufacture*, **34** (12), 479, 481 (*Dec.*, 1959). Work by Boeing Airplane Co. on closed cycle man-algae-*tilapia*-man. *Tilapia* is a Javanese fish.

.7 *Psychology*

(1956) **Studies of isolation and confinement.** G. E. Ruff. *Prepr.*, 1959 *Meeting, Aero Medical Ass.* (*April*, 1959). Fifty subjects observed individually and in groups for periods of one to seven days. Methods used were sociometric rating techniques, direct observation, psychiatric examination, psychological tests, bioelectric measurements and biochemical determinations.

5—AVIATION AND AERODYNAMICS

.2 *Aerodynamics*

[*see also* abstracts nos. 2003–4]

(1957) **Magnetofluidmechanics: Some comments in memory of Donát Bánki.** T. von Kármán. *Acta. Tech. Acad. Sci. Hung.*, **27** (1–2), 41–51 (1959). Elementary theory; possible applications of magnetofluidmechanics, including propulsion of space vehicles.

(1958) **State of the art: dynamics.** *Space-Aeronautics*, **31** (3), 46–7 (*March*, 1959). A review of aerodynamic problems, heat transfer on re-entry and stability.

(1959) **Conduction cuts heating during spacecraft re-entry.** C. B. Neel. *Space-Aeronautics*, **31** (3), 42–5 (*March*, 1959). Recent N.A.S.A. studies show that conduction can make large reductions in surface temperatures and thermal gradients, both to wing leading edges and other areas, during re-entry.

(1960) **A theory for the ablation of glassy materials.** H. A. Bethe and M. C. Adams. *J. Aero. Sci.*, **26**, 321–8, 350 (*June*, 1959). Treats theoretically the ablation of glassy materials by aerodynamic heating. These materials have no distinct solid state and their thermal behaviour allows important simplifications to be made, which give extremely accurate results. Analysis is restricted to the stagnation region of a blunted body, with steady-state ablation. Numerical results are presented for Pyrex. (10 *refs.*)

(1961) **Nose drag in free molecule flow and its minimization.** H. S. Tan. *J. Aero. Sci.*, **26**, 360–6 (*June*, 1959). (17 *refs.*)

.3 *Rocket-Propelled Aircraft*

(1962) **The first spaceship.** M. Caidin. *Astronautics*, **3** (7), 35–7, 75–7 (*July*, 1958). North American X-15.

(1963) **Boost gliders and atmospheric re-entry.** A. J. Eggers. *Interavia*, **14**, 188–90 (*Feb.*, 1959). Discusses the hypervelocity glider as a means of transport, using flight paths at satellite heights and speeds. (7 *refs.*)

(1964) **Pilots beyond the stratosphere.** *Interavia*, **14**, 390–2 (*April*, 1959). Describes the purpose of the X-15 "space aircraft," the problems of protecting the pilot, and experiments in weightlessness.

(1965) **X-15, the world's fastest and highest flying aeroplane.** *Flight*, **75**, 639–43 (8 *May*, 1959). A detailed description of this aircraft with diagrams of its construction and power unit. A description of typical test flights is included.

6—ASTRONAUTICS

.1 *General*

(1966) **High altitude and satellite rockets**. 136 pp., 30s. *Royal Aeronautical Society, British Interplanetary Society, College of Aeronautics* (1958). $15, *Philosophical Library, N.Y.* (1959).

(1967) **High-temperature research in space-vehicle design**. P. E. Glaser. *Arthur D. Little Inc., Washington*, 20 pp. (1958). (11 *refs.*)

(1968) **Our philosophy of space missions**. K. A. Ehricke. *Aero-Space Engng.*, **17** (5), 38–43 (*May*, 1958). Surveys the ability of mankind, and in particular the U.S.A., to make progress in furthering spaceflight. Stresses the need for real imagination and courage.

(1969) **National astronautical program begins to take shape**. I. Hersey. *Astronautics*, **3** (7), 20–3 (*July*, 1958).

(1970) **Space talk: a down to earth glossary of astronautical terms**. 19 pp., gratis, *Republic Aviation Corp., Farmingdale, N.Y., U.S.* (1959). Book.

(1971) **Rocketry and space exploration**. A. G. Haley. 350 pp. 51s., *Van Nostrand, London* (1959). Book.

(1972) **Britain's part in exploring space**. L. R. Shepherd. *Aeroplane*, **96**, 32 (9 *Jan.*, 1959). A note calling for Britain to take a more effective part in space research, by collaboration with other countries if necessary.

(1973) **Outer space before the U.N.** J. A. Joyce. *Flight*, **75**, 88, 92 (16 *Jan.*, 1959). A report, with extracts from speeches, of a United Nations debate on co-operation in the field of outer space.

(1974) **NASA gets off to a fast start**. *Interavia*, **14**, 291–2 (*March*, 1959). Note on the organization of this U.S. Government agency for aeronautical and space research.

(1975) **Vehicles reaching speeds required to overcome the Earth's attraction**. *Flugkorper*, **1**, 18–20 (*March*, 1959). (*In German.*)

(1976) **U.S. space flight projects**. R. M. Loebelson. *Space-Aeronautics*, **31** (3), 38–9 (*March*, 1959). An overall view of the space-exploration programme of the U.S.A.

(1977) **ASME warned against space "panic."** *Aviation Wk.*, **70** (12), 32–3 (23 *March*, 1959). Report of points from papers read to a Los Angeles conference, subjects; space probe rocket performance, comparison of liquid and solid propellent rocket systems, and missile transport and handling.

(1978) **Blue Streak as a space vehicle**. *Aeroplane*, **96**, 384–5 (27 *March*, 1959). Discussion of the possible use of this rocket as a launcher for space probes. Based on paper by W. H. Stephens.

(1979) **Manned space flight is coming**. R. D. Roche. *Soc. Automot. Engrs. J.*, **67** (4), 49–51 (*April*, 1959). A forecast of the reasons for and development time scale of the first manned spacecraft. Spaceflight will develop from military projects, the need for scientific knowledge and for adventure.

(1980) **N.A.S.A. details space missions, needs**. *Aviation Wk.*, **70** (15), 26–9 (23 *April*, 1959). Details of projected satellite and planetary probe launchings as outlined to the U.S. Congress by the National Aeronautics and Space Administration.

(1981) **Chamber simulates space environment**. M. Yaffee. *Aviation Wk.*, **70** (15), 91–6 (23 *April*, 1959). Describes facilities in existence or planned for environmental testing of components and assemblies.

(1982) **NASA reveals its space programme**. *Aeroplane*, **96**, 503–4 (24 *April*, 1959). A report of a recent announcement on plans for satellites and space probes, research on manned re-entry and towards manned expeditions to the Moon.

(1983) **Space research developments in the United States**. J. Maddox. *New Scientist*, **5**, 1065–7 (14 *May*, 1959). A review of plans of NASA for future work on space research and the man-carrying satellite.

(1984) **Britain's opportunities in space research**. H. S. Massey. *New Scientist*, **5**, 1117 (21 *May*, 1959). Note on scope for British contributions.

(1985) **Britain's space prospects**. K. W. Gatland. *Aeroplane*, **96**, 589 (22 *May*, 1959). Comment on parliamentary statements and scientists' proposals for a British programme of space research based on the use of Blue Streak and Black Knight.

(1986) **NASA'S new rocket booster programme**. *Interavia*, **14**, 738–9 (*June*, 1959). Brief descriptions of Scout, Atlas-Able, Atlas-Hustler, Vega, Centaur, Saturn and Nova.

(1987) **Italy's role in space flight**. G. Partel. *Space-Aeronautics*, **31** (6), 282–3 (*June*, 1959). Review of work in progress and projected in Italy.

(1988) **N.A.S.A. proposes nuclear rocket to explore space**. F. E. Rom and P. G. Johnson. *Soc. Automot. Engrs. J.*, **67** (6), 36–40 (*June*, 1959). Describes a low-power nuclear space-rocket, and compares it with chemical and ion-propelled rockets. Suitable boost rockets could be developed in the same time scale. Also discusses Earth-Mars orbits.

(1989) **S.T.L. integrates space probe payload**. I. Stone. *Aviation Wk.*, **70** (22), 55–6, 61, 63–4 (1 *June*, 1959). A general account of the work of Space Technology Laboratories, Inc., particularly in the field of satellite and rocket instrumentation.

(1990) **Canaveral supports space exploration**. *Aviation Wk.*, **68** (24), 187, 189, 191, 193, 195 (16 *June*, 1958). Describes this launching base and the facilities available.

(1991) **Reliability is vital space flight factor**. R. Sweeney. *Aviation Wk.*, **70** (26), 55 (29 *June*, 1959). Report of paper read to an A.R.S. meeting by A. Silvestein on space probe rockets.

(1992) **How far are we on space instrumentation**. E. Stuhlinger. *Space-Aeronautics*, **32** (2), 147, 149, 152, 154–5 (*Aug.*, 1959). A review of the achievements of space probe instrumentation and a forecast of the direction of progress.

.2 *Artificial Satellites*

[*See also* abstracts nos. 1903, 1923, 2156, 2158, 2163, 2167]

(1993) **Optical observations of artificial satellites**. C. Popovici. *Studii Cerc. Astron. Seism.*, **3**, 283–7 (1958). (*In Roumanian.*)

(1994) **Report from the Explorers**. *Astronautics*, **3** (7), 40, 64 (*July*, 1958).

(1995) **Sputnik III—another blow to U.S. prestige**. *Astronautics*, **3** (7), 12 (*July*, 1958).

(1996) **Tendencies in the development of satellite carrying satellites**. O. Scholze. *Flugkorper*, **1**, 21–4 (1959). (*In German.*)

(1997) **Observations of Sputnik III**. P. F. Checcacci and C. Carreri. *Ricerca Scientifica*, **1**, 72–3 (*Jan.*, 1959). (*In Italian.*)

(1998) **Cooling orbital space vehicles**. J. S. Tupper. *Soc. Automot. Engnrs. J.*, **67** (1), 54–5 (*Jan.*, 1959). Proposes the use of water and ammonia evaporative cooling system, with nitrogen as heat transfer fluid.

(1999) **America's ICBM satellite**. *Aeroplane*, **96**, 4 (2 *Jan.*, 1959). Discussion of the Atlas used to receive and retransmit messages while in orbit; project Score.

(2000) **Space research. (a) Artificial satellites. (b) Russian satellites and space rockets**. *Science in Parliament*, (81), 24–25 (20 *Jan.*–26 *March*, 1959). Report of questions in Parliament, 3 Feb., 1959.

(2001) **Satellite optics limited by atmosphere**. J. A. Fusca. *Aviation Wk.*, **70** (4), 75, 77–9, 81, 83–4 (26 *Jan.*, 1959). An account of the effects of the atmosphere on photographic images of the Earth's surface from a satellite. Absorption, scattering, variation of refractive index and turbulence are considered, the most serious problems are those of maintaining image contrast.

(2002) **Problems on artificial satellites of the Earth**. *Amer. J. Phys.*, **27** (2), 90–4 (*Feb.*, 1959). Translation from a Russian journal of problems on satellites suitable for discussion in schools.

(2003) **On the retardation of a satellite**. R. H. Bacon. *Amer. J. Phys.*, **27** (2), 69–72 (*Feb.*, 1959). An explanation of the unexpected decrease in the orbital period of a satellite which moves in a resisting medium.

(2004) **Satellite paradox**. B. D. Mills. *Amer. J. Phys.*, **27** (2), 115–7 (*Feb.*, 1959). A discussion of the velocity increase of a

descending satellite. It is shown that the acceleration in the direction of motion is the same as if the air drag force, reversed, were pushing the satellite.

(2005) **Launching Earth satellites**. *Aeroplane*, **96**, 226–7 (20 *Feb.*, 1959). A survey of the scientific uses and launching of Earth satellites. Contains information on the satellites which had so far been launched, and discusses the scientific knowledge gained from observation of their orbits and the instruments they have carried. A report of paper read to the Royal Aeronautical Society by W. H. Stephens.

(2006) **Biosatellite decompression**. *Space-Aeronautics*, **31** (3), 117 (*March*, 1959). Nomographs for calculating the effects of a perforation in a satellite skin on the internal pressure.

(2007) **Missile detection by satellite**. *Space-Aeronautics*, **31** (3), 157–60 (*March*, 1959). First of two articles on the possibility of detecting isolated ICBM firings.

(2008) **High speed photographic equipment for determining the position of artificial earth satellites**. U. Guntzel-Lingner., *Technik*, **3**, 129–30 (*March*, 1959). (*In German.*)

(2009) **First Scout vehicle delivery due Aug. 15**. *Aviation Wk.*, **70** (11), 26–8 (16 *March*, 1959). General description of the Project Scout general purpose space vehicle and its three- and four-stage versions.

(2010) **NASA reports data on Pioneer IV orbit**. *Aviation Wk.*, **70** (11), 32 (16 *March*, 1959). Details with numerical values of the orbital data for this lunar probe.

(2011) **Atlas-Vega can boost two men into orbit**. *Aviation Wk.* **70** (13), 28–9 (30 *March*, 1959). Short description of projects Atlas-Vega, Saturn and Nova, and some views on ionic-propulsion systems, as reported from Realities of Space Exploration colloquium at the California Institute of Technology.

(2012) **Infrared detection by recon. satellite**. *Space-Aeronautics*, **31** (4), 151–6 (*April*, 1959). Factors affecting an I-R. mapping system, in particular atmospheric transmission, are discussed.

(2013) **Vanguard versus Sputnik**. S. B. Kramer. *Soc. Automot. Engrs. J.*, **67** (4), 90–1 (*April*, 1959). Includes detailed tabular comparison to show how their launching vehicles compare.

(2014) **Project Mercury**. *Flight*, **75**, 485 (10 *April*, 1959). A short description of this project for a manned satellite.

(2015) **Mercury oxygen contract awarded**. *Aviation Wk.*, **70** (15), 33 (13 *April*, 1959). Oxygen system for manned satellite project is to be developed by the AiResearch division of the Garrett Corporation; subcontractors to the McDonnell Aircraft Company.

(2016) **NASA tests models of man-in-space capsule and escape system**. *Aviation Wk.*, **70** (15), 68–9 (13 *April*, 1959). Pictures of models of Project Mercury satellite used for aerodynamics and other tests.

(2017) **N.A.S.A. plans scientific satellite shots**. *Aviation Wk.*, **70** (17), 93 (27 *April*, 1959). Diagrams of multiple-purpose satellite for launching "soon."

(2018) **Bids readied for A.R.P.A. satellite designs**. P. J. Klass. *Aviation Wk.*, **70** (17), 28–30 (27 *April*, 1959). U.S. industry reported to be producing proposals for satellites to help in communications.

(2019) **Eyewitness at Vandenberg**. J. R. Cownie. *Aeroplane*, **96**, 526–8 (1 *May*, 1959). Eyewitness account of the launching of the Discoverer II satellite.

(2020) **Official asks study of deterrent satellite**. P. J. Klass. *Aviation Wk.*, **70** (19), 32–3 (11 *May*, 1959). Report of papers at American Rocket Society Conference in Boston. Subjects include satellite weapon carriers, ion propulsion rockets, a new standard atmosphere proposal and aerodynamic stabilization of satellites.

(2021) **Some exciting possibilities**. N. Calder. *New Scientist*, **5**, 1118–9 (21 *May*, 1959). Proposals for British satellites make possible a large number of investigations, based initially on a payload volume of 1 ft.^{3}

(2022) **What the designer faces in active satellite communications**. *Space-Aeronautics*, **31** (6), 122–5 (*June*, 1959). Report of paper on the design problems of a communications relay satellite system by D. M. Culler.

(2023) **Booster design for a 20,000 lb. satellite**. S. B. Kramer and R. A. Byers. *Space-Aeronautics*, **31** (6), 52–5 (*June*, 1959). Design study of a three-stage booster system based on current state of the art. First stage is recoverable. Detailed analysis of propulsion system, with breakdown of structure and propellent weights for all three stages. Diagrams.

(2024) **NASA plans telescope-bearing satellite**. *Aviation Wk.*, **70** (24), 32–3 (15 *June*, 1959). Points from papers on satellite borne telescopes and the preparation of space crews before space missions.

(2025) **A multi-stage rocket for space research**. K. W. Gatland. *Aeroplane*, **96**, 699–700 (19 *June*, 1959). Description of the Chance-Vought Scout.

(2026) **NASA considers search-rescue satellite**. P. J. Klass. *Aviation Wk.*, **70** (26), 73, 75 (29 *June*, 1959). Proposal to use a satellite to detect and re-radiate distress signals from remote areas.

(2027) **Orbiting flying laboratory transmits physiological information**. *Elect. Engng., N.Y.*, **78** (7), 784–5 (*July*, 1959). Report of lecture by Capt. N. L. Barr (Director of Astronautics Division, U.S. Navy Bureau of Medicine and Survey) at 11th Annual Scientific Assembly of American Academy of General Practice. Mainly electrocardiography.

(2028) **Ten-man space station for assembly in orbit**. S. B. Kramer and R. A. Byers. *Space-Aeronautics*, **32** (1), 52–5 (July, 1959). Proposals for an orbital research station, detailed analysis of weights and services to be installed, suggests this could be in orbit at 500 miles by 1970.

(2029) **Environmental system for Mercury capsule is simple, rugged**. I. Stambler. *Space-Aeronautics*, **32** (1), 42–5 (*July*, 1959). Describes air conditioning and pressurization control for this manned space capsule.

(2030) **Manned space station needs special "ferries and tugs"**. S. B. Kramer and R. A. Byers. *Space-Aeronautics*, **32** (2), 61–3 (*Aug.*, 1959). Designs proposed for a re-entry transport to ferry crew between Earth and space, and an a "astro-tug" for assembling the satellite station in space.

(2031) **Earth-to-space "ferry" designed to carry astronauts**. *Elect. Engng., N.Y.*, **78**, 1234–5 (*Dec.*, 1959). Lockheed and Hughes Aircraft Companies have designed a 4-man space ferry of folding arrow wing configuration, of 14,000 lb. payload.

(2032) **Space agency to attempt to orbit communications sphere in Spring**. *Amer. Metal Market*, **66** (236), 9–10 (8 *Dec.*, 1959). Announcement of Project Echo.

.3 *Lunar and Planetary Probes*

[*See also* abstracts nos. 1992, 2168 and 2170]

(2033) **USAF considers test vehicle family**. *Aviation Wk.*, **68** (24), 175, 177 (16 *June*, 1958). Proposals for a series of multi-purpose space probe launching rockets.

(2034) **The Soviet cosmic rocket**. H. A. Vilter. *Technik*, **3**, 125–8 (1959). (*In German.*)

(2035) **Path around the Sun**. T. Margerison. *New Scientist*, **5** (112), 61–3 (8 *Jan.*, 1959). Describes the orbit of the recently launched Russian space probe, and orbits of other possible probes.

(2036) **Next—Mars and Venus?** H. S. Massey. *New Scientist*, **5** (112), 58–9 (8 *Jan.*, 1959). Reviews the Russian Moon-probe, anticipates that it should now be an easy step to put probes into the neighbourhood of other planets.

(2037) **The Russian planet and its instruments**. R. L. F. Boyd. *New Scientist*, **5** (114), 180–2 (22 *Jan.*, 1959). Details of the range of experiments carried out in this space probe. Describes the instruments involved and discusses them critically in relation to American designs.

(2038) **Solar system reconnaissance**. S. W. Greenwood. *Aeroplane*, **96**, 104–5 (23 *Jan.*, 1959). Describes orbits suitable for space craft exploring the solar system, the velocity requirements and possibility of returning to the vicinity of Earth.

(2039) **Mechta's trip past Moon may have been intentional**. W. A. Daley and D. H. Robey. *Aviation Wk.*, **70** (13), 66–72 (30 *March*, 1959). Discussion of the orbit of the Russian circumsolar probe, and conjecture on what may be discovered with its aid.

(2040) **USAF considering Moon base by 1968**. *Aviation Wk.*, **70** (17), 26–7 (27 *April*, 1959). Report of discussion of requirements for a Moon exploration probe.

(2041) **Britain's part in space exploration**. *Aeroplane*, **96**,

553–5 (8 *May*, 1959). Describes a proposal by the B.I.S. for a Moon-probe vehicle.

(2042) **How Soviets may land man on Moon.** B. Rising. *Aviation Wk.*, **70** (19), 54–5, 57, 61 (11 *May*, 1959). An assessment of the requirements for a Moon-expedition, with detailed weight-analysis.

.4 *Spaceships*

[*See also* abstracts nos. 1918 and 1933]

(2043) **Orientation control for a space vehicle.** General Electric Company (U.S.). *U.S. Pat, No.* 2,856,142. A heavy fluid is pumped through closed circuits disposed about three axes to provide stabilizing forces.

(2044) **How to find thermal equilibrium in space.** R. E. Hess and A. E. Weller. *Aviation Age*, **30** (2), 174–80 (*Aug.*, 1958). Method of determining the equilibrium temperature of a space vehicle described, considering internal sources of heat, radiation and absorption from the surface.

(2045) **State of the art: accessories.** *Space-Aeronautics*, **31** (3), 72, 74, 76, 80, 83–4 (*March*, 1959). Refrigeration systems, power supplies, for hypersonic aircraft and manned space capsules.

(2046) **What instruments for space crews.** G. W. Hoover. *Space-Aeronautics*, **31** (3), 110–2 (*March*, 1959). The problem of supplying the crew with essential information.

.6 *Orbits*

(2047) **On the determination of the orbit of an artificial satellite of the Earth from observations.** E. Marcus. *Studii Cerc. Astron. Seism.*, **3**, 247–53 (1958). (*In Roumanian.*) (2 *refs.*)

(2048) **Guidance for the space age.** C. J. Mundo and E. W. Tooker. *Aero-Space Engng.*, **17** (9), 30–3 (*Sept.*, 1958). Discusses the accuracies required for navigating space craft, an inertial system is described. Proposes the use of an inertial platform and digital computer as the basis of spaceship navigation system.

(2049) **Celestial observations for space navigation.** L. Larmore. *Aero-Space Engng.*, **18** (1), 37–42 (*Jan.*, 1959). Reviews the problems of determining position in regions of the solar system. The accuracy of observation required is about one micro-radian. Sources of systematic error and stable references are discussed.

(2050) **Calculations of satellite orbits.** E. Lenzi and E. Presenza. *Riv. Aero.*, **2**, 233–58 (*Feb.*, 1959). (*In Italian.*)

(2051) **Orbit relationships.** *Space-Aeronautics*, **31** (3), 122–3, 126, 129, 134, 138 (*March*, 1959). Charts displaying orbital quantities for low-eccentricity drag-free paths about a spherical non-rotating earth.

(2052) **Logarithmic spiral: an ideal trajectory for the interplanetary vehicle with engines of low sustained thrust.** R. H. Bacon. *Amer. J. Phys.*, **27** (3), 164–5 (*March*, 1959). It is shown that a vehicle with low sustained thrust can be directed along a logarithmic spiral by means of an extremely simple guidance system: it is possible to choose a spiral for which initial and final velocities are optimum.

(2053) **Accurate position data needed for space course changes.** E. V. Stearns and W. E. Frye. *Space-Aeronautics*, **31** (3), 48–51 (*March*, 1959). A paper on the interdependence of navigational accuracy and thrust power required. Stresses the great accuracy needed to detect errors, and the penalty for making corrections too late.

7—PROPULSION

.1 *General*

(2054) **Aero engines 1959.** *Flight*, **75**, 381–7 (20 *March*, 1959). Describes current engines for light aircraft, helicopters, and transport aircraft, then progresses to developments in those for ballistic missiles. Concludes with a description of the various possible methods of propelling spacecraft and discusses their relative performance, application, and practicability.

(2055) **The development of propulsion units mirrored by literature.** A. R. Weyl. *Luftfahrttechnik*, **5** (4), 130–40 (*April*, 1959). (*In German.*) Considers current development trends in engines for aircraft and space vehicles as evidenced by technical literature. (41 *refs.*)

.3 *Chemical Rockets*

[*See also* abstracts nos. 1907, 1966 and 2165]

GENERAL

(2056) **Radioactive tracers—new aid to rocket instrumentation.** D. E. Shonerd. *Astronautics*, **3** (7), 30–1, 64, 66 (*July*, 1958).

(2057) **Testing giant rocket engines.** D. M. Tenenbaum and W. Sprattling. *Astronautics*, **3** (7), 28–9, 44, 46 (*July*, 1958).

(2058) **Choosing rocket parameters.** W. J. Reinhardt. *Space-Aeronautics*, **31** (3), 54–6 (*March*, 1959). The criteria which help an engine designer to choose between striving for a higher specific impusle or a lower dry weight.

(2059) **Aircraft and spacecraft propulsion.** A. M. Rothrock. *Canad. Aero J.*, **5** (5), 172–83 (*May*, 1959). Discusses propulsion systems including rockets for both aircraft and space vehicles. Solid and liquid propellents are compared, as are nuclear-thermal and nuclear-electric propulsion. Concludes that the move towards rocket propulsion for both types of craft has brought a great need for additional research work.

(2060) **Combustion instability . . . what are its causes and cures.** K. R. Stehling. *Space-Aeronautics*, **32** (1), 46–7 (*July*, 1959). Lists the possible causes of instability and oscillation in combustion chambers, and the harmful effects.

(2061) **Motors for guided weapons.** *Interavia*, **14**, 968–9 (*Aug.*, 1959). Pictures of exhibits at the Paris Air Show, 1959.

.31 SOLID-PROPELLENT ROCKETS

(2062) **New development trends in solid propellent rockets.** W. Trommsdorff. *Luftfahrttechnik*, **5** (2), 46–8 (*Feb.*, 1959). (*In German.*) Recent solid-propellent rocket design has tended to emphasize the development of high specific impulses sometimes at the expense of combustion chamber factor (motor case/charge weight). Suggests that a higher all-burnt velocity could be achieved by low-pressure stable-burning propellents (*e.g.*, plastic fuels) in chambers of glass-reinforced resin.

(2063) **Liquid injection for solid rocket thrust control.** M., Grenus. *Space-Aeronautics*, **31** (4), 59–63 (*April*, 1959). Evaluation of three typical liquids (water, ethylene oxide, and hydrogen peroxide-hydrazine mixture) for solid rocket thrust control. Effects of injection on thrust variables are shown, and propulsion system and overall missile weight penalties and thrust control ranges are discussed.

(2064) **Packaged propulsion.** K. W. Gatland. *Aeroplane*, **96**, 679–81 (12 *June*, 1959). Description of Polaris and its two-stage solid propellent rocket system.

.32 LIQUID-PROPELLENT ROCKETS

(2065) **Gas producing apparatus especially for rocket type propulsion devices.** D. Napier and Son Ltd. *U.S. Pat. No.* 2,852,916. A power-gas-producing apparatus for a hydrogen-peroxide/fuel rocket.

(2066) **Rocket stand pressure controller design.** G. E. Click and R. G. Halliday. *Aero-Space Engng.*, **17** (5), 72–7 (*May* 1958). Analysis for design purposes of a control system for maintaining a constant pressure in gas-pressurized propellent tanks during the expulsion of the liquid.

(2067) **Design of liquid rocket engines.** N. E. Konovalov. *Vestnik Vozdushnogo Flota*, 44–52 (*June*, 1958). (*In Russian.*)

(2068) **New wrinkle in fuelling rockets.** *Astronautics*, **3** (7), 34, 66–7 (*July*, 1958).

(2069) **Gamma.** *Flight*, **75**, 120 (23 *Jan.*, 1959). Description of this four-combustion-chamber rocket engine made by Armstrong Siddeley for use in Black Knight.

(2070) **"Atlas" propulsion unit.** *Luftfahrttechnik*, **5** (2), 57 (*Feb.*, 1959). (*In German.*) Brief details of this rocket engine.

(2071) **Combustion in liquid-fuel rocket motors.** D. B. Spalding. *Aero. Quart.*, **10** (1), 1–27 (*Feb.*, 1959). Provides a simplified picture of the processes in liquid bi-propellent rocket motors. Droplet vaporization, chemical reaction and drag between gas and droplet are considered, quantitative theroretical results are presented for variation of droplet size and velocity, and gas temperature and velocity within the chamber. The theory is applied to the V-2 rocket motor. (8 *refs.*)

(2072) **Rocket performance problems.** *Aeroplane*, **96**, 199–200 (13 Feb., 1959). Report of a paper by S. L. Bragg, which discusses performance limitations, chamber and injector design, cooling problems and instability.

(2073) **X-15 engine will have wide space use.** M. Yaffee. *Aviation Wk.*, **70** (13), 59–65 (30 *March*, 1959). Pictures and description of Reaction Motors XLR-99 rocket engine of 50,000 lb. thrust.

(2074) **Rocketdyne looks ahead.** *Aeroplane*, **96**, 652–3 (5 *June*, 1959). Review the current programme for large rocket motor development now proceeding in the U.S.A. 20 million pound thrust engine clusters are envisaged.

(2075) **Development problems of rocket engines for ballistic missiles.** T. F. Dixon. *Interavia*, **14**, 818–21 (*July*, 1959). A review, by the Chief Engineer of Rocketdyne, of problems experienced in developing large thrust rocket engines, and a look at their future possibilities.

.33 PROPELLENTS

(2076) **A thermal layer mechanism of combustion of solid-composite propellents.** R. F. Chaiken. *Paper presented at Western Section of Combustion Institute meeting at University of California at Berkeley* (23–4 *June*, 1958).

(2077) **Cyanogen and hydrogen cyanide studied for high energy rockets.** K. R. Stehling. *Space-Aeronautics*, **31** (2), 62 (*Feb.*, 1959). Note on research on these fuels with liquid oxygen or fluorine as oxidants.

(2078) **Principal development trends of modern rocket fuels.** A. Dadieu. *Luftfahrttechnik*, **5** (4), 123–30 (*April*, 1959). (*In German.*) Reviews desirable characteristics of fuels, attention is paid to light elements. Higher specific impulses are discussed with particular reference to borane and hydrazine, there is also scope in the field of solid propellents. Free radicals and nuclear energy are also considered as sources of propulsive energy. (18 *refs.*)

(2079) **Synthetic chemicals may replace chemical fuels in rocket engines.** M. Yaffee. *Aviation Wk.*, **70** (12), 30 (23 *March*, 1959). Reports of investigations into the usefulness of diethyl-cyclohexane and related cyclic hydrocarbons as rocket fuels.

(2080) **Storable liquid propellents look good for drone rockets.** R. P. Reul. *Space-Aeronautics*, **32** (1), 75–6, 78, 81 (*July*, 1959). Propulsion scheme for target aircraft uses bi-propellent rocket engines for boost and cruise. Suitable and unsuitable propellents are listed.

(2081) **Plastisol propellent unveiled.** *Chem. Engng. News*, **37** (30), 22–3 (27 *July*, 1959). Describes a solid propellent made from polyvinyl chloride, a plasticiser, ammonium perchlorate and aluminium, and processes used in its manufacture at Atlantic Research of Alexander, Va., U.S.A.

.4 *Nuclear Rockets, Working Fluid*

[*See also* abstracts nos. 1988 and 2059.]

(2082) **The characteristics of hydrogen and water as working gases for reactor-heated rocket motors.** I. Sänger-Bredt. *Astronautica Acta*, **3**, 241–80 (1957). [Available in English as N.A.S.A.-TT-F-I.] [See also abstract No. 506, *J.B.I.S.*, **16**, 552 (*Sept.-Oct.*, 1958).]

(2083) **Nuclear rocket effort acceleration urged.** *Aviation Wk.*, **70** (12), 28–9 (23 *March*, 1959). Report of testimony on rocket development and space rocket propulsion plans given to a committee of the U.S. House of Representatives.

.6 *Miscellaneous*

(2084) **Electric arc plasma generators for propulsion.** G. Partel. *Riv. Aero.*, **2**, 275–87 (*Feb.*, 1959). (*In Italian.*)

(2085) **Republic broadens space, missile fields.** J. S. Butz. *Aviation Wk.*, **70** (26), 47–8 (29 *June*, 1959). Report includes a description of this firm's work on a plasma jet engine.

8—MISSILES

.1 *General*

[*See also* abstract no. 1966.]

(2086) **British missiles and rockets.** J. Pellandini. *Fusées*, **3**, 29–33 (*April*, 1958). (*In French.*)

(2087) **Ground testing missile fuel systems.** A. J. Rothenberg and C. Hermanski. *Missile Design Devel.*, **4** (7), 12–13, 15–16 (*July*, 1958).

(2088) **Setting up an off-site missile test center.** W. W. Withee. *Astronautics*, **3** (7), 26–7, 73–5 (*July*, 1958).

(2089) **Why missile launchings fail.** P. T. Nelson. *Soc. Automot. Engrs. J.*, **67** (1), 58–9 (*Jan.*, 1959). Handling equipment and ground-based components of missile weapon systems are analysed critically, proposals for increasing reliability are given.

(2090) **Development of guided missiles in Great Britain.** A. R. Weyl. *Luftfahrttechnik*, **5** (2), 49–54 (*Feb.*, 1959). (*In German.*) An account of the development of guided missiles in Britain; some retarding influences are described. Surveys technical features of certain missiles, ballistic rockets and guidance systems.

(2091) **Sahara test centre.** C. Ducarre. *Flight*, **75**, 213 (13 *Feb.*, 1959). Describes the French missile test centre C.I.E.S.S. at Colomb-Bechar.

(2092) **Missile production at Douglas.** *Interavia*, **14**, 252–3 (*Mar.*, 1959). Pictures of production lines for Nike-Hercules and Thor.

(2093) **French begin rocket testing in Algeria.** *Aviation Wk.*, **70** (13), 65 (30 *March*, 1959).

(2094) **U.S. missile tour.** K. Owen. *Flight*, **75**, 514, 517 (17 *April*, 1959); 565–6 579–80 (24 *April*, 1959); 596–8 (1 *May*, 1959); 644–5 (8 *May*, 1959). An account of the military organization and facilities of the United States presented in four parts: I, Thor guidance and propulsion and the Air Force Ballistic Missile Division; II, aircraft, missiles and satellites in fabulous Las Vegas; III, Strategic Air Command and Cape Canaveral; IV, Cape Canaveral and Air Research and Development Command.

(2095) **Farnborough 1958. Missiles (Second part).** G. Bruner. *Docaero*, **56**, 23–30 (*May*, 1959). (*In French.*) Descriptions of Short Bros. G.P.V. and SX-A-5, Armstrong-Whitworth "Sea-Slug," English Electric "Thunderbird," Bristol "Bloodhound" and Saunders-Roe "Black Knight." (11 *refs.*)

(2096) **External wire fins give compact missile heat-exchangers.** J. Stambler. *Space-Aeronautics*, **31** (5), 77–82 (*May*, 1959). Discussion of new types of extended-surface heat exchangers.

(2097) **Premier western missile range.** J. R. Cownie. *Aeroplane*, **96**, 572–4 (15 *May*, 1959). Description with map and illustrations of the 5000-mile missile testing range with launching sites at Cape Canaveral and observation posts in the West Indies and at sea.

(2098) **Services for guided weapons.** *Aeroplane*, **96**, 629 (29 *May*, 1959). Gives instances of the part flexible pipes and tubes play in making a missile.

(2099) **Missiles.** L. Bölkow. *Luftfahrttechnik*, **5** (6), 198–208 (*June*, 1959). (*In German.*) Missiles are defined and their history recounted. The main branches of missile technology are described, propulsion and aerodynamics in some detail. A system of classification is given.

(2100) **Standard of development of missiles.** E. Sänger. *Luftfahrttechnik*, **5** (6), 209–17 (*June*, 1959). (*In German.*) Tabular presentation of the characteristics and state of development of the world's missiles. The most important of recent trends of development are also outlined.

(2101) **Missile fuel sloshing simulated**. C. Lewis. *Aviation Wk.*, **70** (24), 81, 83 (15 *June*, 1959). An account of test equipment to help solve problems of motion of liquids in missile tankage.

(2102) **British missiles over Australian deserts**. *Interavia*, **14**, 835–7 (*July*, 1959). The Woomera range has played and is playing an important part in the trials programmes of British guided weapons and space probe rockets.

(2103) **Missile testing in the Sahara**. *Interavia*, **14**, 838–9 (*July*, 1959). Description of the French missile range near Colomb Béchar.

(2104) **The missile show—Europe—U.S.A.** *Interavia*, **14**, 932–4 (*Aug.*, 1959). Pictures of missile exhibits at the Paris Air Show, 1959.

(2105) **Prime missile headache: clean stage separation**. K. R. Stehling. *Space-Aeronautics*, **32** (2), 42–5 (*Aug.*, 1959). A review of different methods of breaking the strong mechanical joint necessary between successive stages without causing internal damage or disturbing the motion of the rocket.

.2 *Short-Range*

(2106) **Anti-missile missile base concepts**. I. A. Greenfield. *Missile Design Devel.*, **4** (7), 17–18 (*July*, 1958).

(2107) **The anti-missile—a myth?** E. Burgess. *Interavia*, **14**, 170–2 (*Feb.*, 1959). Problems of detecting and intercepting ICBMs discussed.

(2108) **British test vehicle designed for easy parts access**. R. Hawthorne *Space-Aeronautics*, **31** (2), 66–8, 72, 74, 78, 80 (*Feb.*, 1959). Description of Short Bros. G.P.V. and launching and trials equipment.

(2109) **Re-entry research: the Lockhead X-17**. *Flight*, **75**, 181 (6 *Feb.*, 1959). Describes this test rocket vehicle.

(2110) **Shell for the Seaslug**. *Flight*, **75**, 212 (13 *Feb.*, 1959). Description of package in which this missile is transported.

(2111) **Integrated seals simplify Tartar design**. W. Haas. *Space-Aeronautics*, **31** (4), 89–92 (*April*, 1959). Describes arrangements for sealing outer skin of this missile.

(2112) **Missiles to stop missiles?** T. Margerison, *New Scientist*, **5**, 733–5 (2 *April*, 1959). Discussion of the economics of anti-missile missiles. Many would be needed for each attacker and the cost would be prohibitively high.

(2113) **Tests to failure boost Sparrow I reliability**. E. H. Derr. *Space-Aeronautics*, **32** (1), 133–4, 138, 141 (*July*, 1959). Discusses the use of laboratory environmental testing in missile development.

.3 *Ballistic*

(2114) **Supporting research and ballistic missiles**. L. G. Dunn. *Astronautics*, **3** (7), 24–5, 80–3 (*July*, 1958).

(2115) **Defence research: Ballistic missiles (infra-red detection)**. *Science in Parliament*, (81), 5 (20 *Jan.*–26 *March*, 1959). Report of Questions in Parliament, 23 Feb., 1959.

(2116) **"Gun barrel" launching saves ICBM's first stages**. V. M. Tyler, E. C. Jackson, and R. M. Pierce. *Space-Aeronautics*, **31** (2), 52–4 (*Feb.*, 1959). Proposal to launch large rocket vehicles from vertical shafts thousands of feet long by generating gas below and evacuating above the vehicle. 30% of the launch weight might be saved.

(2117) **Atlas ABC**. *Flight*, **75**, 182 (6 Feb., 1959). Pictures and short description of three development stages.

(2118) **Titan: new angles on a new ICBM**. *Flight*, **75**, 245–6 (21 *Feb.*, 1959). Photographs of Titan and a short account of its development and use.

(2119) **Optimised boost system staging**. *Space-Aeronautics*, **31** (3), 118–9 (*March*, 1959). Charts based on the Malina-Summerfield optimization criterion for multi-stage rocket vehicle design.

(2120) **An unrealistic policy for defence**. P. J. de la Ferté. *New Scientist*, **5** (120), 506–8 (6 *March*, 1959). Challenges the decision to use ICBMs from fixed bases, emphasizes the importance of mobility as posessed by the long-range bomber and missile-carrying submarine.

(2121) **Missile-age production**. *Flight*, **75**, 313–4 (6 *March*, 1959). Illustrated description of assembly lines for Atlas, Jupiter, and Thor.

(2122) **Underground dispersion of long-range ballistic weapons**. E. Burgess. *Interavia*, **14**, 412–4 (*April*, 1959). The trend towards "hard," *i.e.*, well protected, ICBM launching sites complicates the problems of servicing and keeping them in readiness.

(2123) **Ballistic missile reliability**. P. W. Powers. *Interavia*, **14**, 424–5 (*April*, 1959). The importance of reliability in the effectiveness of a ballistic weapons system.

(2124) **Design of a 2,500-mile missile**. *Aeroplane*, **96**, 434–5 (10 *April*, 1959). Report of paper by E. C. Cornford read to Royal Aeronautical Society which discusses payload ratio, specific impulse, control and re-entry heating and acceleration problems.

(2125) **Pacific range to play big tracking role**. R. Hawkes. *Aviation Wk.*, **70** (11), 86–7 (16 *March*, 1959). A proposed reorganization of the missile and satellite tracking stations of the U.S. in the Pacific area.

(2126) **Load cells measure Atlas thrust and weight to 50 lb**. R. J. Carleton. *Space-Aeronautics*, **31** (4), 115, 118 (*April*, 1959). Describes arrangement of thrust cells for X, Y and Z components of thrust and for weight measurement.

(2127) **Speed marks Jupiter development**. E. Clark. *Aviation Wk.*, **70** (15), 54–67. (13 *April*, 1959). Describes and illustrates organization of military units which fire Jupiter IRBM.

(2128) **Progress report on Thor**. J. R. Cownie. *Aeroplane*, **96**, 501–3 (24 *April*, 1959). Discusses the history of development of Thor and the organizations concerned. Propulsion and guidance systems are described with notes on the firms responsible.

(2129) **Thor production at Douglas**. J. R. Cownie. *Aeroplane*, **96**, 552–3 (8 *May*, 1959).

(2130) **Jets control Titan nose cone's attitude**. *Aviation Wk.*, **70** (19), 28–9 (11 *May*, 1959). Pictures and a short description of attitude control system for re-entry of Titan nose cone.

(2131) **Bomarc to be combat-ready at year end**. R. Hawkes. *Aviation Wk.*, **70** (19), 72–3, 75–6, 81–5 (11 *May*, 1959). Description and pictures of missiles in production, the missile guidance system and operational use.

(2132) **Thors for the R.A.F.** *Flight*, **75**, 713–5 (22 *May*, 1959). Describes the production and use of the missile briefly, includes a part-section annotated diagram.

(2133) **Hardware at Hatfield**. *Flight*, **75**, 739 (29 *May*, 1959). Pictures of ballistic missile test towers at de Havilland Aircraft, with a short description.

(2134) **The missile gap**. *Aeroplane*, **96**, 626–7 (29 *May*, 1959), Discussion by S. F. Singer of the relative ballistic missile strengths of Russia and the United States.

(2135) **Integrated support expedites launching**. R. Sweeney. *Aviation Wk.*, **70** (22), 70–1, 73, 76, 79–80 (1 *June*, 1959). Transportation, handling, and launching equipment for Atlas.

(2136) **Aiming a ballistic missile**. *Aeroplane*, **96**, 654–5 (6 *June*, 1959). A note on the accuracy required to set up a missile on its launching pad and method for doing it.

(2137) **Development of a modern ICBM**. *Interavia*, **14**, 812–6 (*July*, 1959). Information on Titan, a description of production methods and production inspection. Preparation for firing and test firing facilities are described, as installed at the Denver plant of Martin Aircraft Co.

(2138) **Manufacturing the Atlas at Convair**. *Interavia*, **14**, 810–11 (*July*, 1959). Description of the construction of Atlas.

(2139) **The Jupiter rolls off the assembly line**. *Interavia*, **14**, 984–5 (*Aug.*, 1959). Photographs and a short description of production and testing of Jupiter's structure.

(2140) **Hydraulics packs power for missile erection**. G. D. Shaw. *Space-Aeronautics*, **32** (2), 77–80, 82 (*Aug.*, 1959). A report on a hydraulically powered erector used in Polaris tests. Fine control of position is necessary, equally important is the need for smooth motion and the avoidance of accelerations liable to damage thin-skinned missile structures.

.4 *Upper Atmosphere Research*

[*See also* abstract no. 1966.]

(2141) **Soviet rockets on show.** *Flight*, **75**, 283 (27 *Feb.*, 1959). A page of pictures of high-altitude rockets and instrument containers from a Moscow exhibition.

.6 *Guidance and Control*

(2142) **Tridac, flight simulator for guided missiles.** J. J. Gait. *Fusées*, **3**, 10–20 (*April*, 1958). (*In French.*) (6 *refs.*)

(2143) **Missile guidance.** P. C. Gaudillère. *Fusées*, **3**, 26–8 (*April*, 1958). (*In French.*) (8 *refs.*)

(2144) **Guidance problems of guided missiles.** M. Perret. *Fusées*, **3**, 21–5 (*April*, 1958). (*In French.*)

(2145) **Guidance and control problems in the Air Force ballistic missile program, Part I.** J. C. Fletcher. *Aero-Space Engng.*, **17** (5), 50–4 (*May*, 1958). Discusses guidance analysis, control system problems and radio guidance problems.

(2146) **Infrared application to guidance and control.** R. W. Powell and W. M. Kaufman. *Aero-Space Engng.*, **17** (5), 66–71 (*May*, 1958). Discusses use of visible light, infrared, and radar for long-range detection of airborne targets. Infrared offers the only passive method, is difficult to countermeasure, and is useful both day and night. Some drawbacks are mentioned, but the availability of equipment and low cost are big advantages.

(2147) **The problem of guiding anti-aircraft missiles.** B. Stückler. *Luftfahrttechnik*, **5** (2) 38–45 (*Feb.*, 1959) (*In German.*) Deals with remote control, target location and the use of infra-red detection; kinematics of missile trajectories and the problems of choosing suitable ones.

(2148) **Lax specs cause confusion in rate gyro field.** N. W. Battermann. *Space Aeromautics*, **31** (4), 159, 161–2, 165, 168 (*April*, 1959). A warning against the use of ambiguous terms and inadequately specified test procedures. Performance characteristics of rate gyros are defined.

(2149) **Researchers explore exotic gyros.** J. Holaban. *Space-Aeronautics*, **31** (5), 130–3 (*May*, 1959). Review of theory and basic operation of gyros using inherent angular momenta of electrons and protons.

(2150) **Stable platforms for inertial guidance.** *Aeroplane*, **96**, 654 (5 *June*, 1959). Picture and description of a missile component.

(2151) **Inertial guidance for long-range aircraft and missiles.** *Interavia*, **14**, 822 (*July*, 1959). A note on the need for inertial guidance, a list of firms working on it, and some of the current uses.

(2152) **Reliability in inertial systems.** A. M. Voutsas and W. T. Chow. *Interavia*, **14**, 823 (*July*, 1959). An account of methods of production and test of gyroscope and computer components of inertial guidance systems at the Bosch Arma Corporation's works, New York.

(2153) **Infrared missile homing proves simplest, most accurate.** W. J. Haywood. *Space-Aeronautics*, **32** (2), 131–3 (*Aug.*, 1959). Short discussion of the problems of determining line-of-sight to target with an array of infra-red detectors, and the use of this information in the autopilot.

9—RADIO AND ELECTRONICS: COMMUNICATIONS

(2154) **Lockheed switches to PAM-FM.** W. J. Cox. *Aviation Age*, **30** (2), 138–42 (*Aug.*, 1958). Describes advantages of pulse amplitude modulation for transmitting missile data over a frequency modulated carrier link.

(2155) **Telemetry progress: R.F. link for space with today's hardware.** H. Scharla-Nielsen. *Aviation Age*, **30** (2), 144–5 (*Aug.*, 1958). Nomograms for attenuation of signals in interplanetary communication links.

(2156) **Reliability and stability most critical in satellite communications.** *Space-Aeronautics*, **31** (1), 38–45 (*Jan.*, 1959). Problems of the development of communications links with satellite relays are discussed. Equipment reliability, stability of operation, and the accuracy with which high gain aerials must be oriented are the chief ones.

(2157) **ONERA telemetry.** H. de Boiteux and G. Mousette. *Rech. Aéronaut.*, **68**, 3–7 (*Jan.*, 1959). (*In French.*) Describes the characteristics of the ONERA developed telemetry system, gives the accuracy of systems at present in use and in the course of development.

(2158) **Radio tracking of Earth satellites.** D. R. Moorcroft. *Amer. J. Phys.*, **27** (2), 73–86 (*Feb.*, 1959). The characteristics of satellite orbits are related to an observer on the Earth's surface. The theory of orbit determination from doppler observations of the satellite transmitter is developed, and extended to the use of an interferometer aerial array.

(2159) **Space communications.** *Space-Aeronautics*, **31** (3), 120–1 (*March*, 1959). Charts for design of communication links, transmitter power, choice of frequency and time lag variation with distance.

(2160) **State of the art: electronics.** *Space-Aeronautics*, **31** (3), 61–3, 65 (*March*, 1959). The problems raised by space-flight in the development of suitable electronic systems; weight, power sources, choice of operating frequency and aerial systems are discussed.

(2161) **Evaluating A.P.U. systems for spacecraft.** S. L. Sandelman and R. W. McJones. *Space-Aeronautics*, **31** (3), 86, 88, 90, 92, 94, 97 (*March*, 1959). Various energy storage systems analysed for their suitability for auxiliary power systems. Optimum weight criteria for given power output and duration are defined.

(2162) **Shock ionisation changes E.M. propagation characteristics.** W. Sisco and J. M. Fiskin. *Space-Aeronautics*, **31** (3), 66, 68, 70 (*March*, 1959). The effects of ionization produced by hypersonic shock waves on the communications systems of space-craft.

(2163) **Sputnik II carried corner reflectors.** *Aviation Wk.*, **70** (13), 41 (30 *March*, 1959). Observations of *Sputnik II* with a monopulse tracking radar set discussed at Institute of Radio Engineers meeting.

(2164) **Solar cell R & D shooting for 16-22 per cent. efficiencies.** J. I. Davies. *Space-Aeronautics*, **31** (4), 44–6 (*April*, 1959). Design considerations for solar cell systems, with emphasis on electro-mechanical and thermal factors. Research and development programmes to improve efficiencies and find new ways of producing cells are reviewed. Graphs of silicon solar cell characteristics and configurations of oriented systems.

(2165) **R.F. loss through rocket flame easy to figure.** R. J. Schmelzer. *Space-Aeronautics*, **31** (4), 171–8 (*April*, 1959). Gives method for determining the propagation loss from exhaust flame ionization.

(2166) **Energy in space: pounds versus power.** H. A. Zahl, H. K. Ziegler and A. F. Daniel. *Chem. Engng. News*, **37** (20), 96–9, 133 (18 *May*, 1959). A discussion of power sources for electronic equipment of space vehicles, the conditions they experience, alternative energy sources, and types used in satellite vehicles so far. Concludes that chemical batteries are best of available types for short period use, fuel cells when available can provide for intermediate durations, and solar cells, already in use, for long durations.

(2167) **Orbital communications.** *Aeroplane*, **96**, 627–8 (29 *May*, 1959). Describes experiments in reflecting radio signals from the Moon, suggests the use of passive reflectors and relay transmitters in satellites as part of a communications system.

(2168) **Mechta telemetry, instruments detailed.** *Aviation Wk.*, **70** (26), 53 (29 *June*, 1959). Diagram of arrangements within this solar probe.

(2169) **Miniature television system developed.** *Elect. Engng., N.Y.*, **78**, 787 (*July*, 1959). TV camera 7½ in. × 2¼ in. dia., weighing 42 oz., developed by Lockheed Missiles and Space Division; possible applications indicated.

(2170) **Are we ready for space probe data transmission?** W. F. Sampson. *Space-Aeronautics*, **32** (1), 124–7 (*July*, 1959). Discusses problems of noise levels, receiver, aerial, and power supply design.

(2171) **Vibration proofing for missile electromechanics.** R. S. Dillon. *Space-Aeronautics*, **32** (2), 46–9 (*Aug.*, 1959). Account of the methods of test and design problems of components for Snark. (4 *refs.*)

(2172) **An elementary design discussion of thermoelectric generation.** E. W. Bollmeier. *Elect. Engng., N.Y.*, **78** (10), 995–1002 (*Oct.*, 1959).

The following abstracts refer to books noted in this issue: 1897–8, 1901, 1910, 1912, 1966, 1971.

BOOK REVIEWS

Aircraft and Missile Propulsion. Volume II. The Gas Turbine Power Plant, the Turboprop, Turbojet, Ramjet, and Rocket Engines. By M. J. Zucrow. 9×5¾ in. Pp. xiv+636, illustrated. 1958. New York: John Wiley and Sons, Inc. ($13); London: Chapman and Hall, Ltd. (104s.).

The author, in his preface, says that this book "... *discusses the methods for analyzing and determining the performance characteristics of the gas-turbine power plant, the turboprop engine, the turbojet engine, the ramjet engine, the liquid-propellent and the solid-propellent engine*".

This is the second of three volumes to appear under the main heading of Aircraft and Missile Propulsion by the author. The first was reviewed in *J.B.I.S.*, 1959–60, **17**, 112.

The present volume is divided into the following sections: (1) Gas-Turbine Power-Plant Cycles and Analysis of Ideal Cycles, (2) Analysis of Gas-Turbine Power Plants and the Turboprop Engine, (3) The Turbojet Engine, (4) The Ramjet Engine, (5) Rocket Jet Propulsion. The last-mentioned section contains an introduction to rocket flight in addition, though why vehicles powered by air-breathing engines are not similarly honoured appears to be a mystery.

Reheat is dealt with, but by-pass and ducted fan engines are not mentioned, nor are combination engines such as the turbojet within the ramjet duct, as used on the Nord Griffon II.

The book has a distinctly academic flavour. The presentation is tidy, but occasionally oversimplified. Oversimplification is useful in indicating trends without overtaxing the reader, but can give results that would be seriously in error in a specific case. The author does not always emphasize the limitations of his assumptions.

In a text prepared by a Professor, it is a little surprising to this reviewer to see rocket specific impulse defined as thrust per unit *weight* rate of consumption of propellents. Academic people have some responsibilities here in presenting fundamentals as logically as possible. In astronautics, in particular, mass and weight need to be handled in a discriminate fashion. Thrust results from the flow of mass, and the definition of specific impulse should correspond.

As with the first volume, the references quoted throughout the book vary widely in their usefulness. Some of the immediate post-World-War-II articles mentioned are of no current technical value, and of limited historical interest. In contrast, the author omits to refer to Clark's classic contribution of 1945 (*Wireless World*, 1945, **51**, 305) when discussing stationary satellites for continuous short-wave communication on the Earth's surface, and refers instead to an American paper dated 1947.

Much the same material as is contained in this book can be found in other texts already published. A particularly useful feature of this work is the large number of worked examples throughout the text, and the inclusion of many exercise problems together with their answers. This will appeal to students, for whom the author states that the book is primarily intended. Moreover, a wide field is treated within the covers of a single volume, and this is possibly attractive to the young propulsion engineer who feels he'd like a single text of his own ready to hand.

S. W. GREENWOOD.

Entwicklungsstand 1957 der unbemannten Flugkörper, Überschall-Fluggeräte und Raumfahrzeuge. Von Eugen Sänger (Mitteilungen aus dem Forschunginstitut für Physik der Strahlantriebe e.v., Stuttgart, No. 12), 30 × 21 cm. Pp. 143, with 1 fig. October, 1957. München: R. Oldenbourg.

The present effort on rocket-(or otherwise) propelled flight vehicles will steadily increase, but with a few selected types only. Though there are definite signs of increased spending on the civilian side, the main emphasis is still on military applications, and in a few years' time East and West will be in the position of obliterating each other and both together of reverting the Earth into a dead planet. However, all hope is not lost yet if the politicians play their part in preventing this from happening before the year 1970. Because by then there is likely to be no further use for military rockets, and with that, presumably, for H-bombs. From then on, all the efforts will be on civilian application and by the year 2000 man will probably travel through space with photon rockets at the rate of 10^8km./hr., the velocity of light. These are two of the conclusions which the author arrives at in his investigation.

The paper proper is divided into two main parts. Taking the second one (94 pp.) first, about 250 flight vehicles (mainly military) which were at the time of writing in the planning, research, development or production stage on both sides of the iron curtain, are listed in sixteen categories ranging from supersonic fighters to manned space vehicles. All available unclassified information is gathered, such as: type, authority, contractor, state of development or production, cost; details about fuselage, propulsion system, booster, navigation, performance, armament (warhead), etc. In the case of the U.S. Air Force I.C.B.M. Atlas, this fills a full page. The collected data are taken from unnamed technical journals, and these are blamed for "possible inaccuracies."

The first part of the paper (38 pp.) is entitled "Some political aspects to supersonic aviation and spaceflight." Here the information from the second part is analyzed and discussed together with statements (some of which are quoted) by Heads of Governments, Defence Ministers, military experts, etc., Military, economic, technical, scientific, cultural and other aspects are considered.

Future trends are indicated, some of which are mentioned above. The usefulness of the anti-missile missile is doubted. It is likely, however, that other defence means, perhaps "high-energy rays," may become available and will be of such instantaneous and destructive power as to render any threat from the air meaningless, and thus make war a thing of the past (*Did not Alfred Nobel think his invention of Dynamite would have a similar effect?*). The U.S.A. and U.S.S.R. will then probably continue spending vast sums for the exploitation of high-speed aviation and spaceflight. In this, a United Europe will have to play its part, no individual European country being able to bear the cost of development.

The author hopes that his paper will help in showing the need for spaceflight and he thinks that spaceflight will eventually secure world peace. To this even Pope Pius XII gave his blessing, as is quoted in an abstract from the Pope's address to the International Astronautical Congress in Rome in 1956.

Scientists are often accused of not giving thought to the political and humanitarian implications of their achievements. Well, Sänger has done it here. F. C. JESSEN.

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